

---

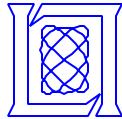
# Radiometric Calibration and Flight Validation\*

Jeffrey A. Mendenhall

Advanced Space Systems and Concepts  
Group

MIT/Lincoln Laboratory

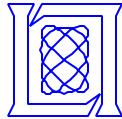




# Outline

---

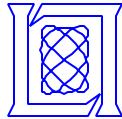
- **Radiometric Calibration**
  - Review of MIT/LL Integrating Sphere System
  - Technique
  - Analysis
  - Results
  - Landsat Transfer Radiometer Study
- **Flight Validation**
  - Techniques
  - Results
    - Stability
    - Absolute Radiometry
  - Stray Light
- **Summary**



# Outline

---

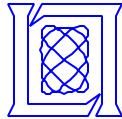
- **Radiometric Calibration**
  - Review of MIT/LL Integrating Sphere System
  - Technique
  - Analysis
  - Results
  - Landsat Transfer Radiometer Study
- **Flight Validation**
  - Techniques
  - Results
    - Stability
    - Absolute Radiometry
  - Stray Light
- **Summary**



### Pre-Flight Methodology:

- **Objective: Calibrate ALI gain, linearity, temperature dependence, repeatability**
  - Flood focal plane with uniform beam from large integrating sphere
  - Monitor beam with NIST traceable detectors
  - Spectroradiometer for incident spectrum knowledge
- **Calibration of integrating sphere output radiance agrees with GSFC measurements within 2% between 440 and 900 nm**

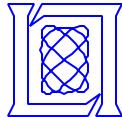




# MIT/LL Radiometric Integrating Sphere System

---

- **30" Diameter Sphere Produced by *Labsphere Inc.***
  - Spring of 1997
- **Spectrareflect Inner Coating**
- **10" Diameter Output Port**
- **3 Internally Mounted 150 W Halogen Lamps**
- **1 Externally Mounted 125 W Halogen Lamp**
- **4 Externally Mounted 400 W Xenon Lamps**
- **2 Digitally Controlled Aperture Selectors**
  - Between Externally Mounted Halogen Lamp and Sphere
  - Between Externally Mounted Xenon Lamp and Sphere
- **Broadband Si and Ge Detectors Mounted to Sphere to monitor sphere stability**



# Radiometric Calibration Method

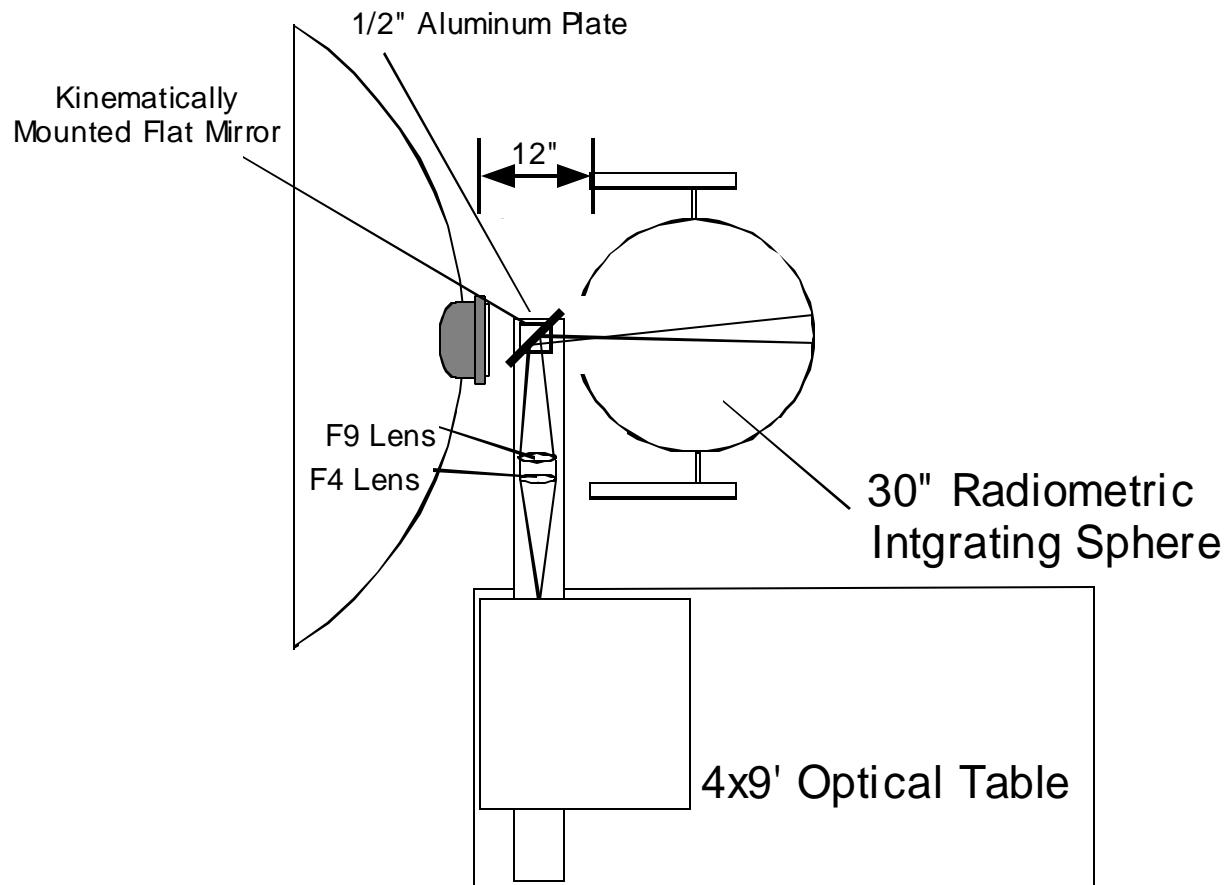
---

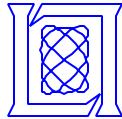
- Flood focal plane with uniform beam from 0 to 110% expected reflected radiance levels in 5% intervals
- Collect 300 dark and illuminated frames for each interval
  - All pixels
- Monitor beam with NIST traceable detectors:
  - Radiometers for stability
  - Spectroradiometer for incident spectrum knowledge
- Repeat selected measurements:
  - Repeatability
  - Minimum, maximum, and expected focal plane and focal plane electronics operating temperatures
  - Different integration periods



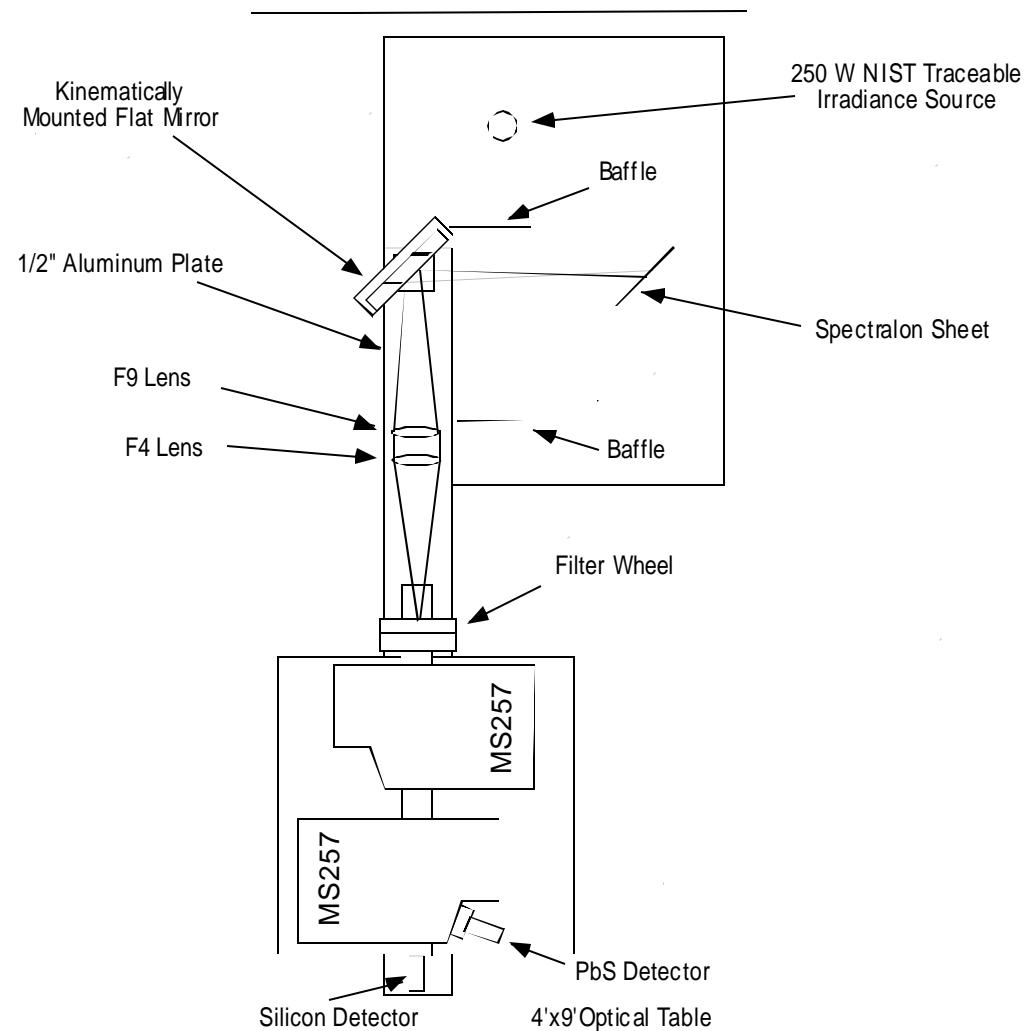
# Radiometric Calibration Set-Up

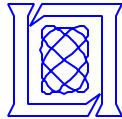
---





# Spectroradiometer

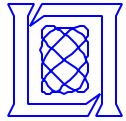




# Radiometric Calibration Data Analysis

---

- Derive Output Radiance of Integrating Sphere for Each Level
  - Apply spectroradiometric corrections for NIST traceability
- Calculate In-Band Radiance for Each Band and Each Level
  - Sphere radiance estimate
  - Vacuum tank window transmission
  - Spectral response of ALI
- Obtain Response of Each Pixel for Each Level
  - Dark frame subtraction
  - Average of 300 frames
- Fit Response of Each Pixel Individually
  - Linearity as a function of integration time (ms)
  - Linearity as a function of radiance ( $\text{mW/cm}^2/\text{sr/m}$ )



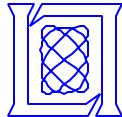
# Radiometric Calibration Data Analysis

---

- In-band Radiance Calculations:

$$R_P (\text{mW} / \text{cm}^2 / \text{sr} / u) = P_r(dn) C_P (\text{mW} / \text{cm}^2 / \text{sr} / u / dn)$$

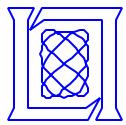
- $R_P$  is the in-band response for pixel P
- $P_r$  is the digital response for pixel P
- $C_P$  is the derived radiometric calibration coefficient



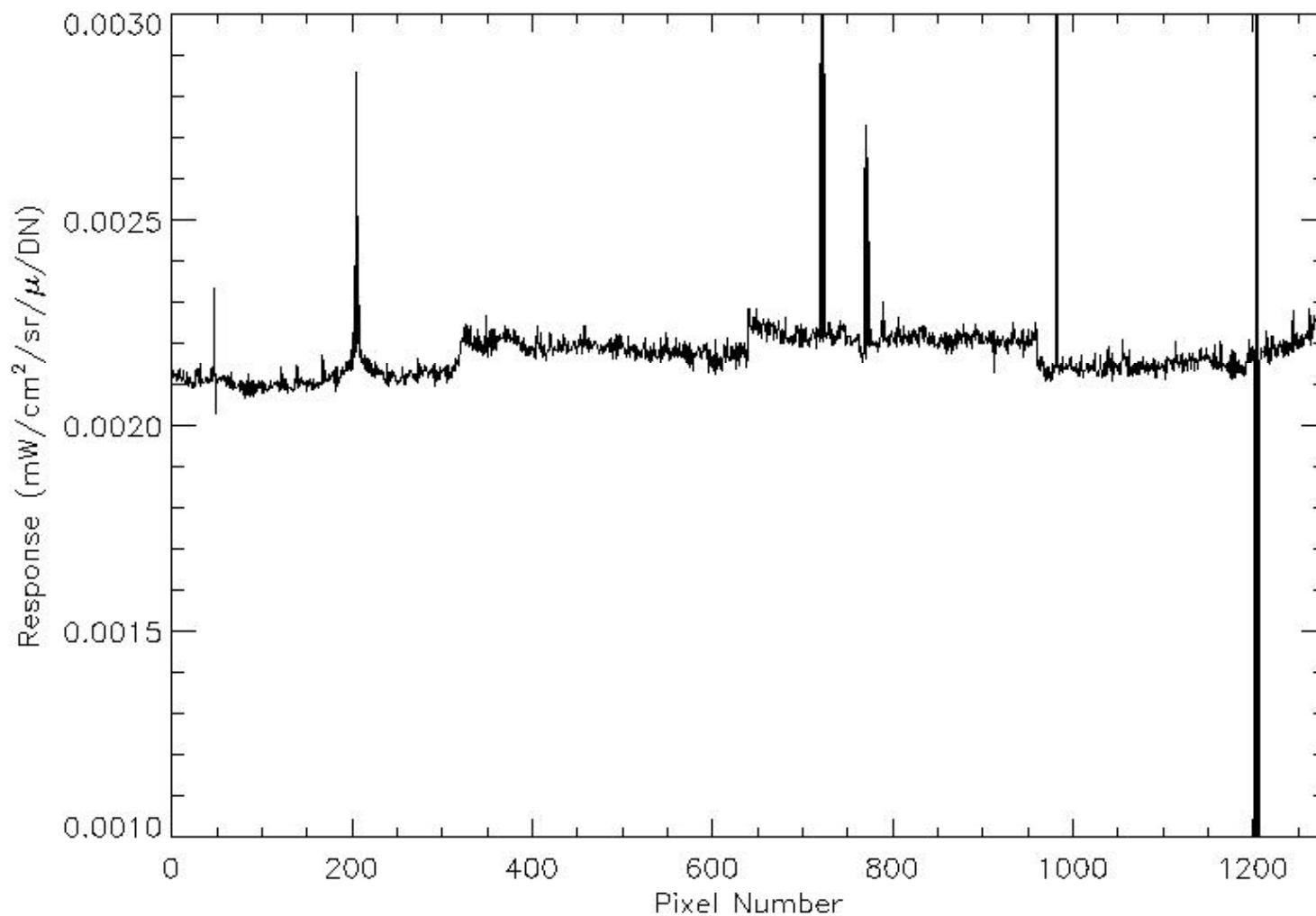
# Radiometric Calibration Error Budget

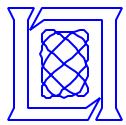
---

Source	1s Error (%)		
	600 nm	1300 nm	2000 nm
NIST Standard Lamp	0.875	0.94	1.535
Spectralon Panel	0.67	0.67	0.67
Spectroradiometer Repeatability	0.67	0.67	0.67
Spectroradiometer Detectors	0.67	1.0	1.0
Integration Sphere Repeatability	0.33	0.33	0.33
Integrating Sphere Uniformity	0.67	0.67	0.67
Vacuum Window Transmission	0.33	0.67	0.67
ALI repeatability	0.33	0.33	0.33
<b>Total (sum in quadrature)</b>	1.7%	1.97%	2.32%

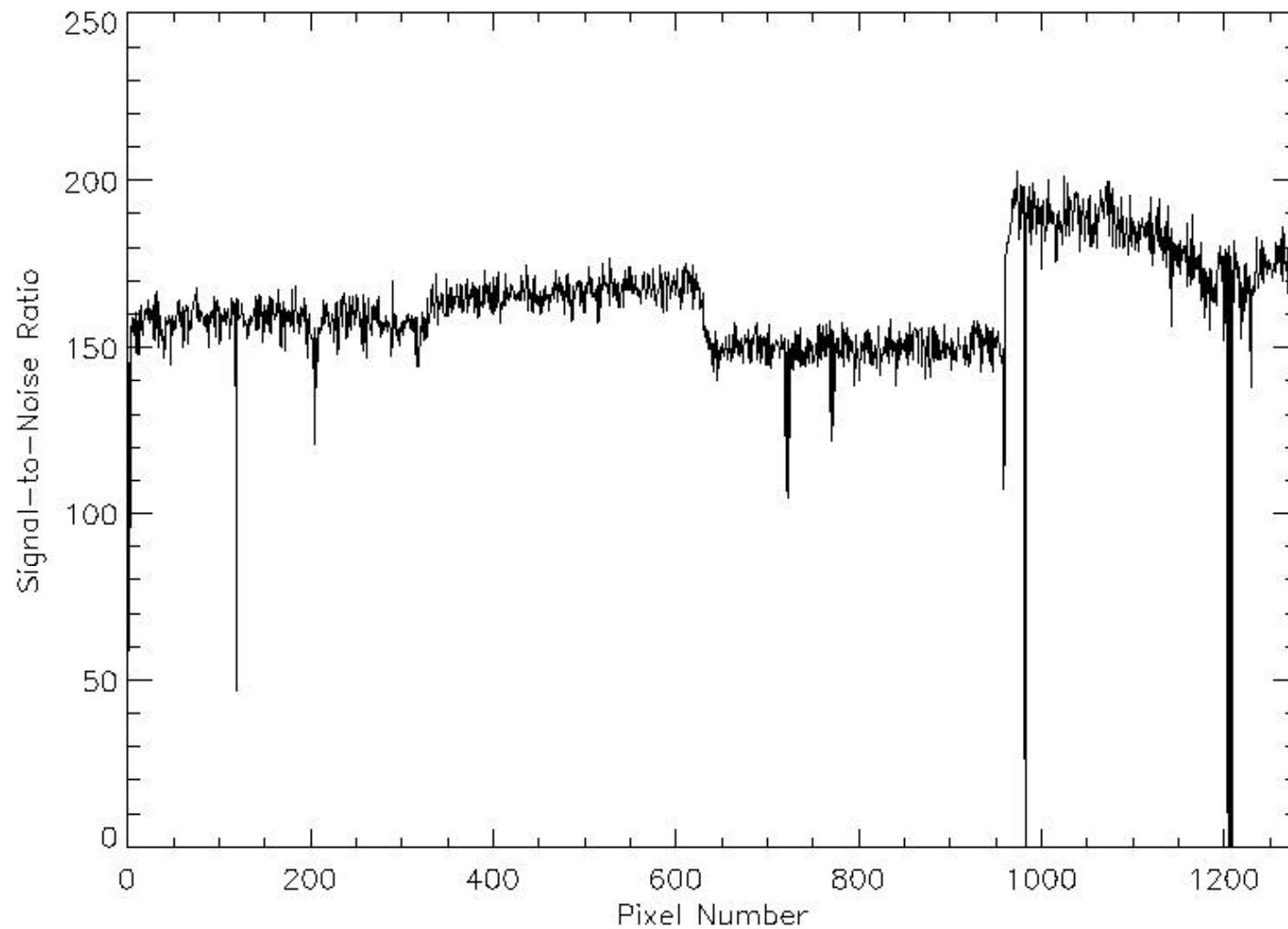


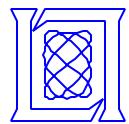
# Radiometric Calibration Results: Band 5 Coefficient





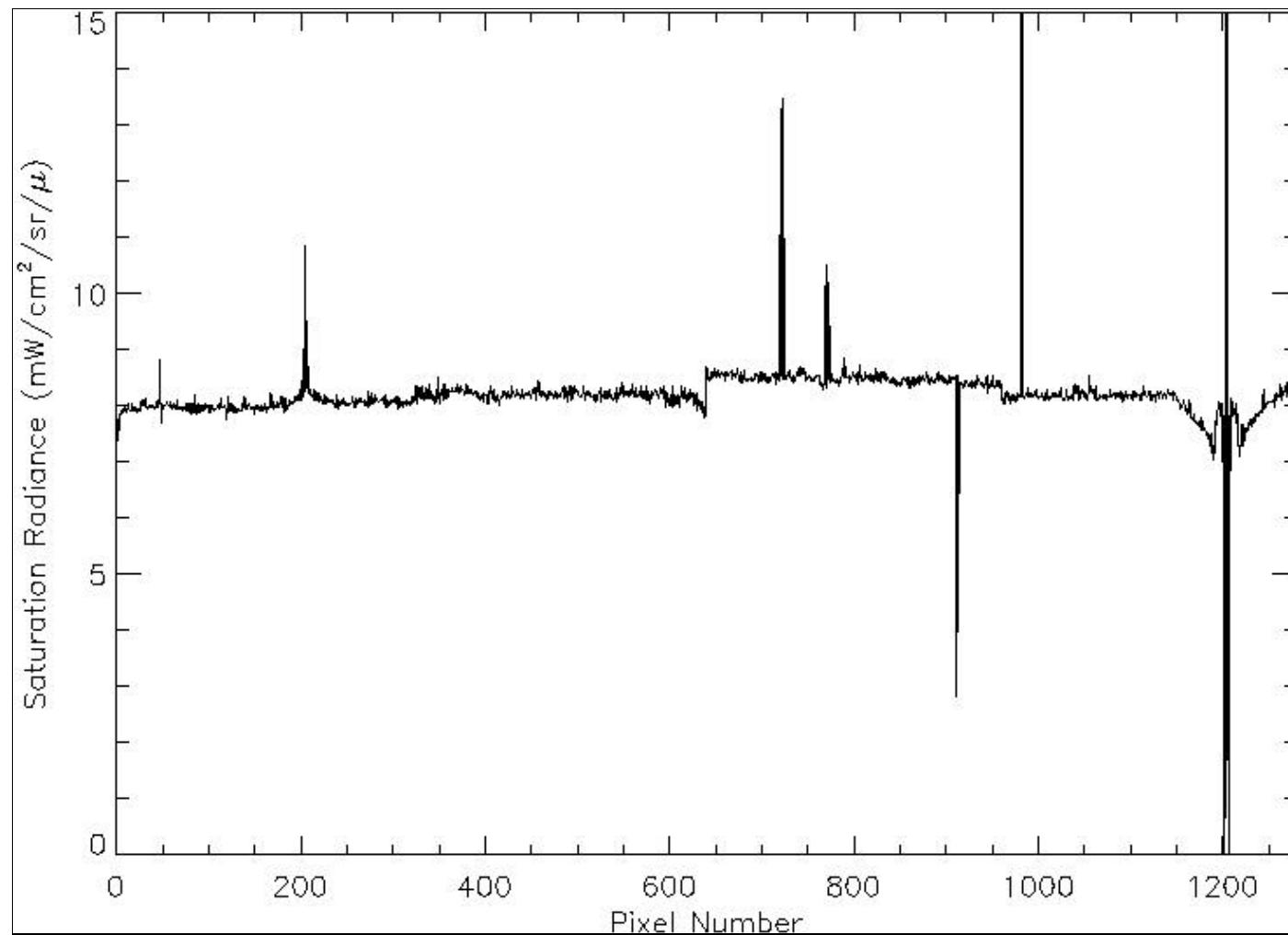
# Radiometric Calibration Results: Band 5 SNR

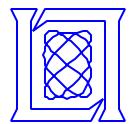




# Radiometric Calibration Results: Band 5 Saturation Radiance

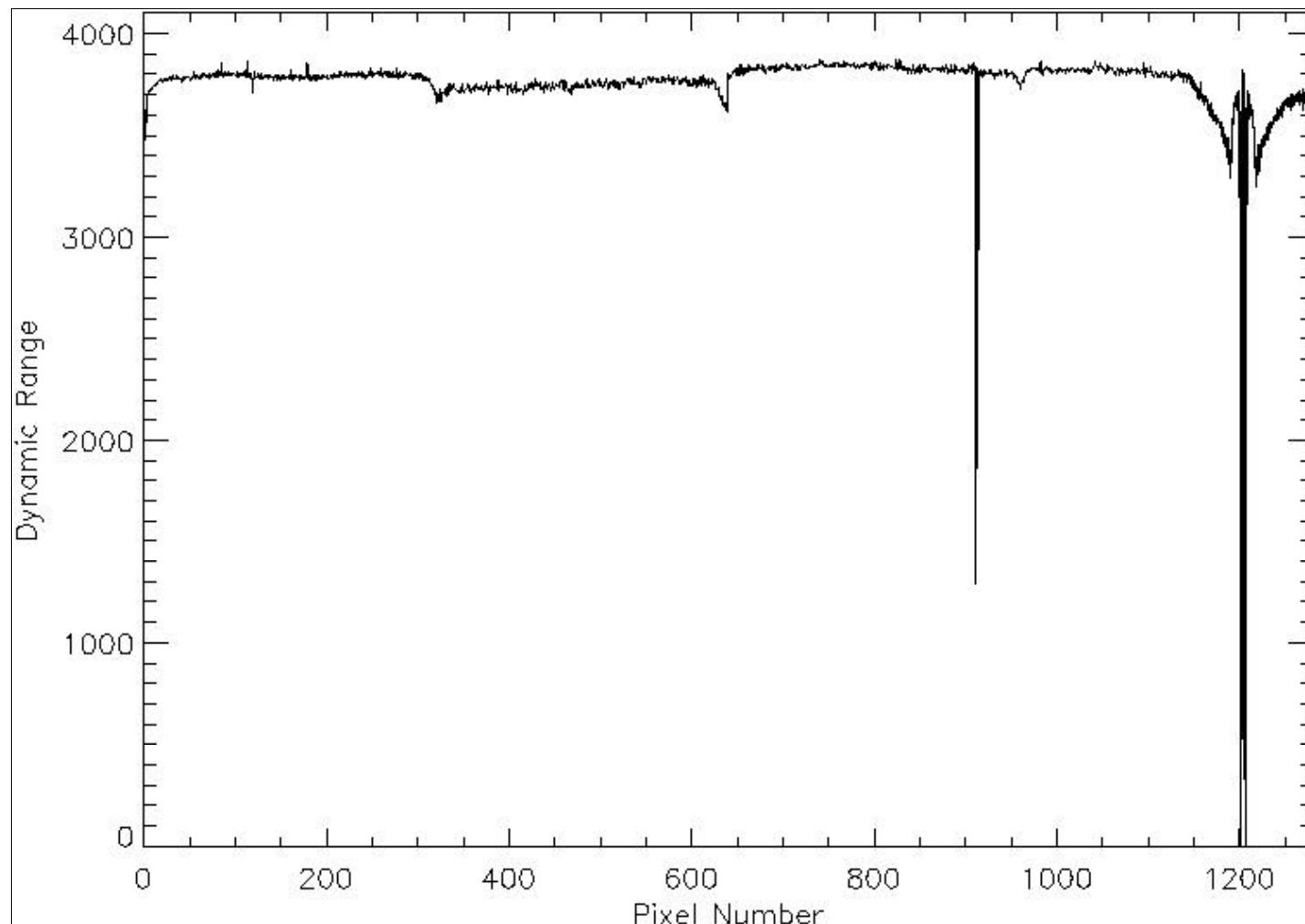
---

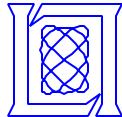




# Radiometric Calibration Results: Band 5 Dynamic Range

---

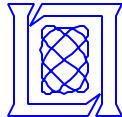




# Landsat Transfer Radiometer Study

---

- Compare in-band radiance measurements obtained with Landsat Transfer Radiometer (LXR) and calculated in-band radiances based on spectroradiometric measurements of MIT/LL integrating sphere
- Provide radiometric link between Landsat sensors and ALI
- LXR Bands
  - Four bands similar to Landsat ETM+ bands 1,2,3,4
  - Two narrow bands centered at 440 nm and 660 nm



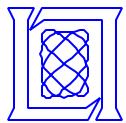
# Landsat Transfer Radiometer Study

---

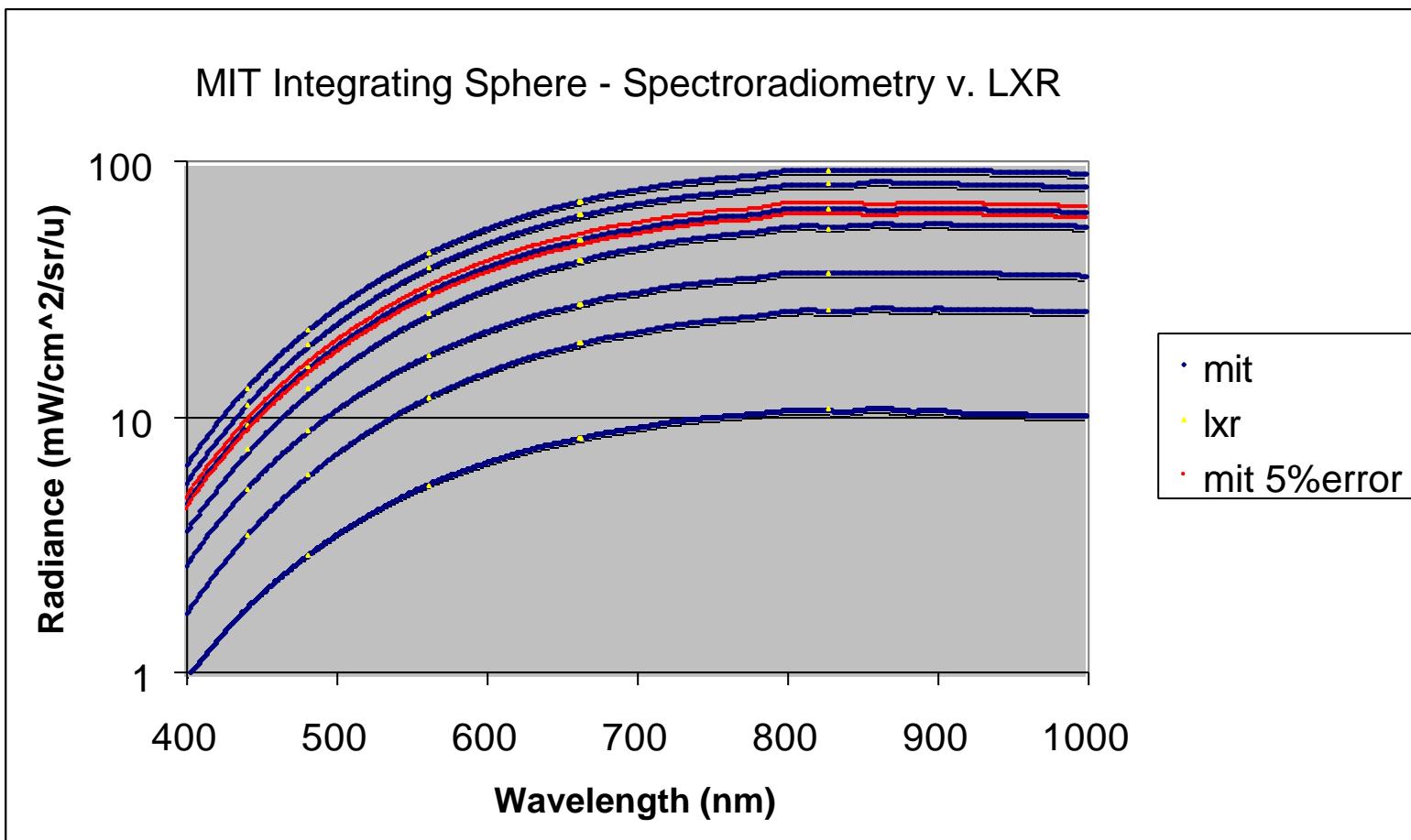
- Spectroradiometric Calculations:

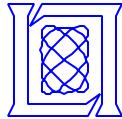
$$L(c,s) = \frac{\int RSR(c,l) L_l(s,l) dl}{\int RSR(c,l) dl}.$$

- **L(c,s)** is the calculated spectral response weighted spectral radiance for band C and level s
- **RSR(c,l)** is the LXR relative spectral response for band c
- **L(s, l)** is the spectroradiometrically measured spectral radiance of the MIT/LL integrating sphere
- Units for this comparison are mW/cm<sup>2</sup>/sr/m



# Results of Landsat Transfer Radiometer Study

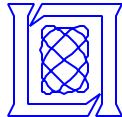




# Outline

---

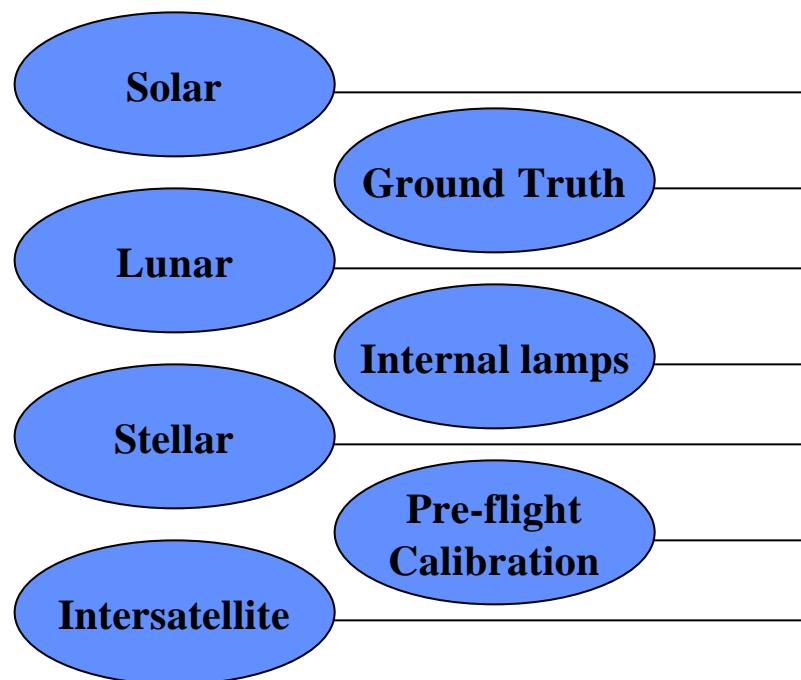
- Radiometric Calibration
  - Review of MIT/LL Integrating Sphere System
  - Technique
  - Analysis
  - Results
  - Landsat Transfer Radiometer Study
- Flight Validation
  - Techniques
  - Results
    - Stability
    - Absolute Radiometry
  - Stray Light
- Summary



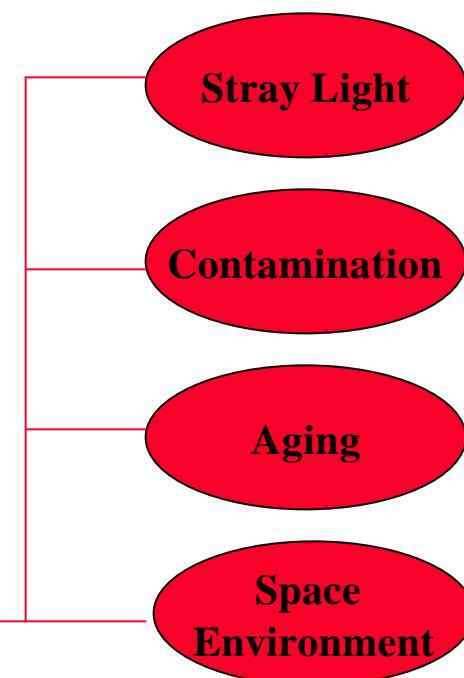
## On-orbit Radiometric Performance Assessment

- **Objective: Absolute measurement of scene flux at every detector**
  - All bands
  - Varying scene intensities
  - Long term stability

### Tools

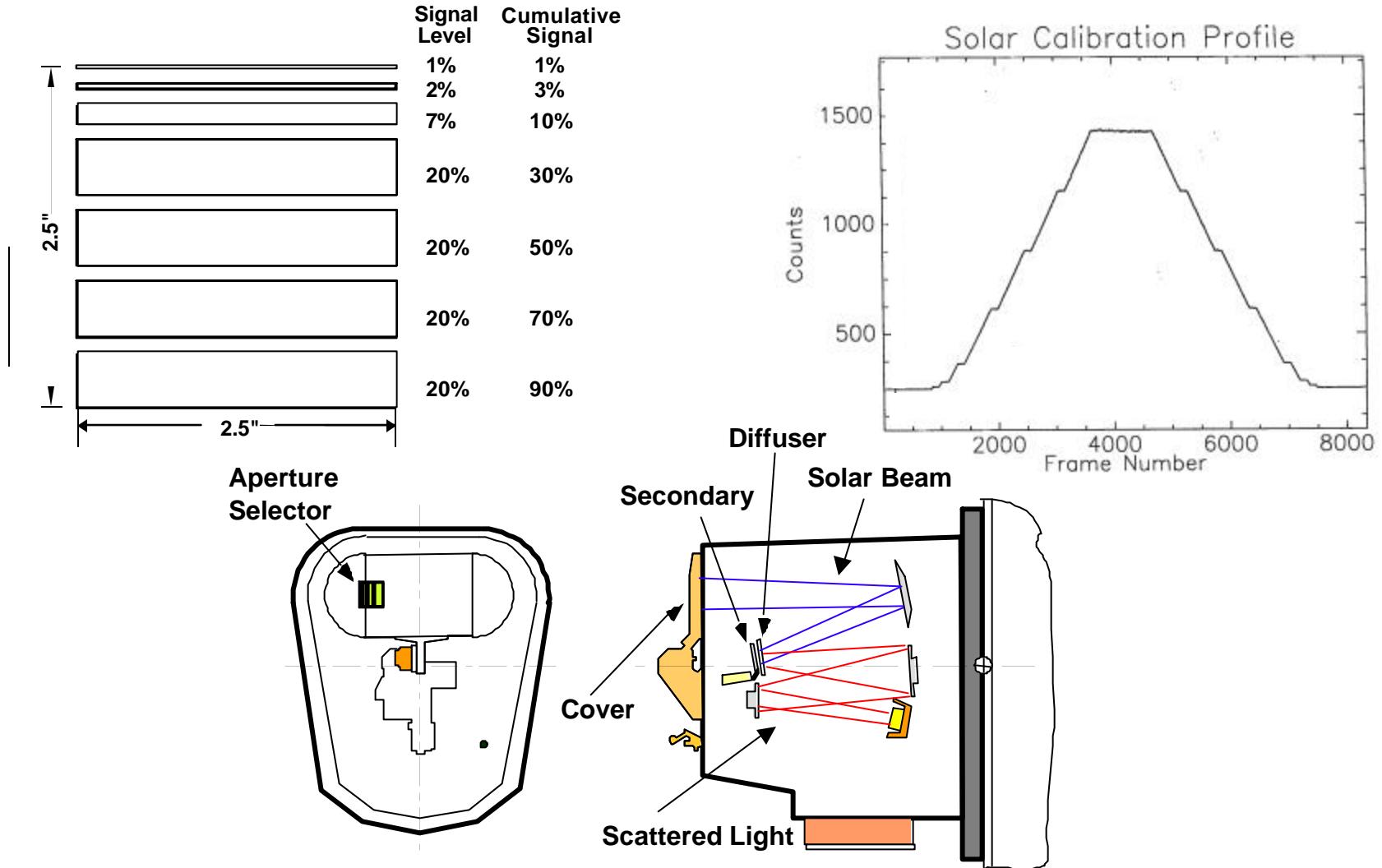


### Challenges





## Solar Calibration



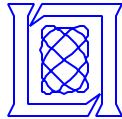


## Radiometric Calibration

---

- **Lunar Calibration**
  - Calculate Lunar spectral irradiance ( $E_M(l)$ )  
Account for geometric effects and phase dependencies
  - Compare to SeaWifs Lunar spectral irradiance measurement
  
- **Intersatellite Comparison**
  - Landsat 7
  - Over 10 Sites Compared
  - Compared Bands 1, 2, 3, 5, 7 due to similarity of spectral responses
  - Terra comparisons forthcoming





## Radiometric Calibration

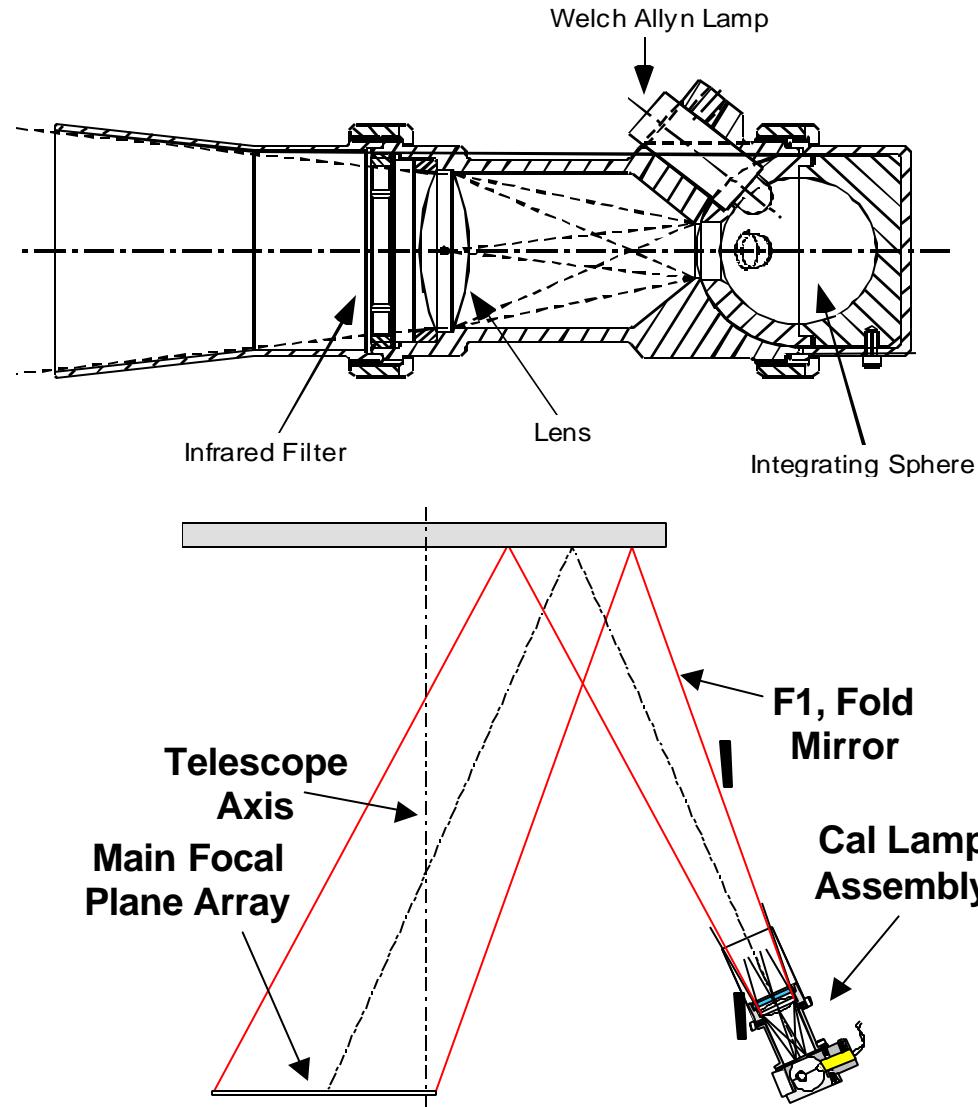
---

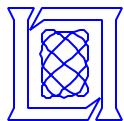
- **Ground Truth Referencing**
  - Lake Frome, Australia ground truth collected by CSIRO.
  - Barreal Blanco and Arizario Argentina ground truth collected by U. of Arizona and U. of Colorado
  - Ivanpah Playa and Railroad Valley ground truth collected by U. of Arizona
  - AVIRIS underflights





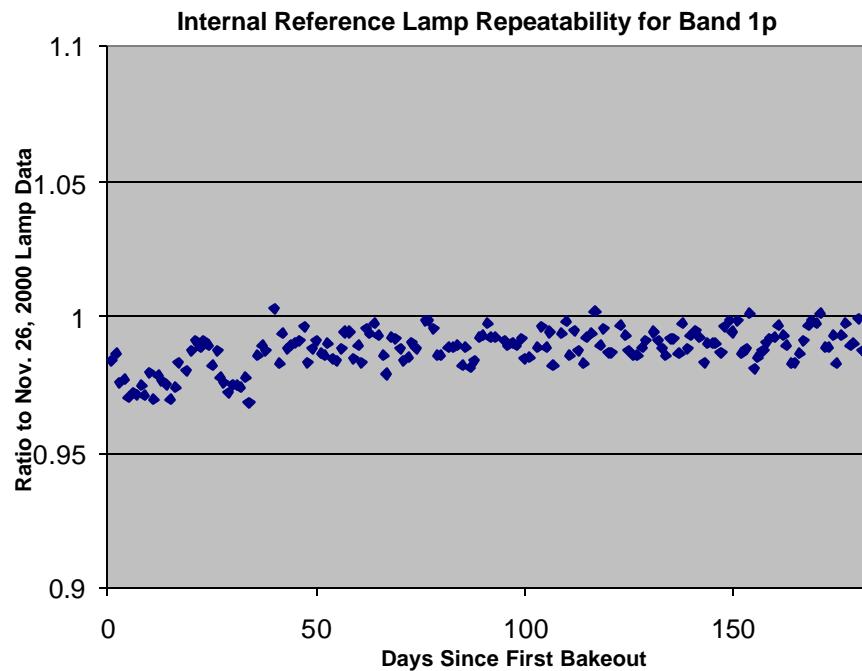
# Internal Reference Lamps



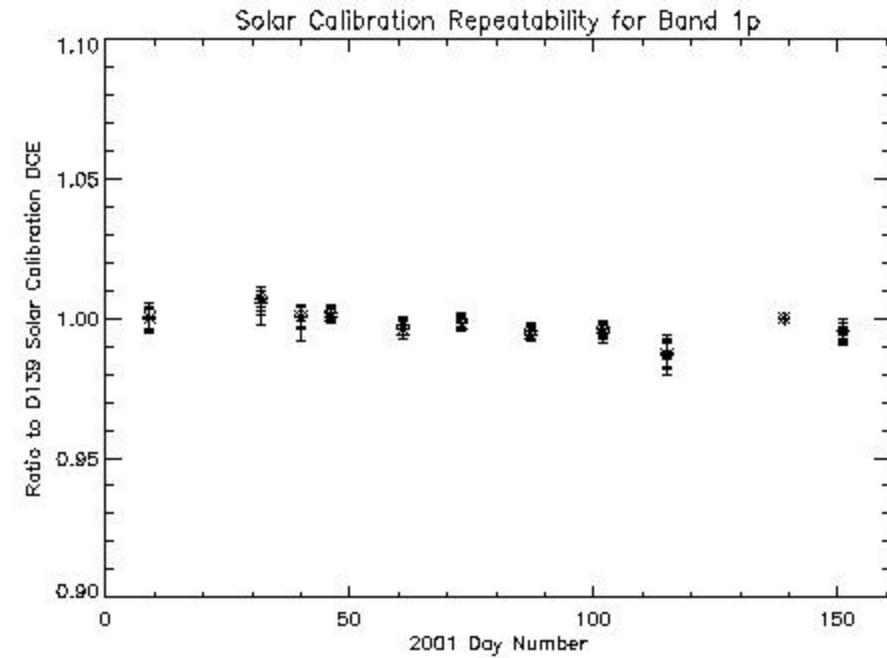


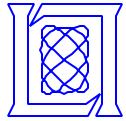
# Instrument Stability

## Internal Reference Lamps

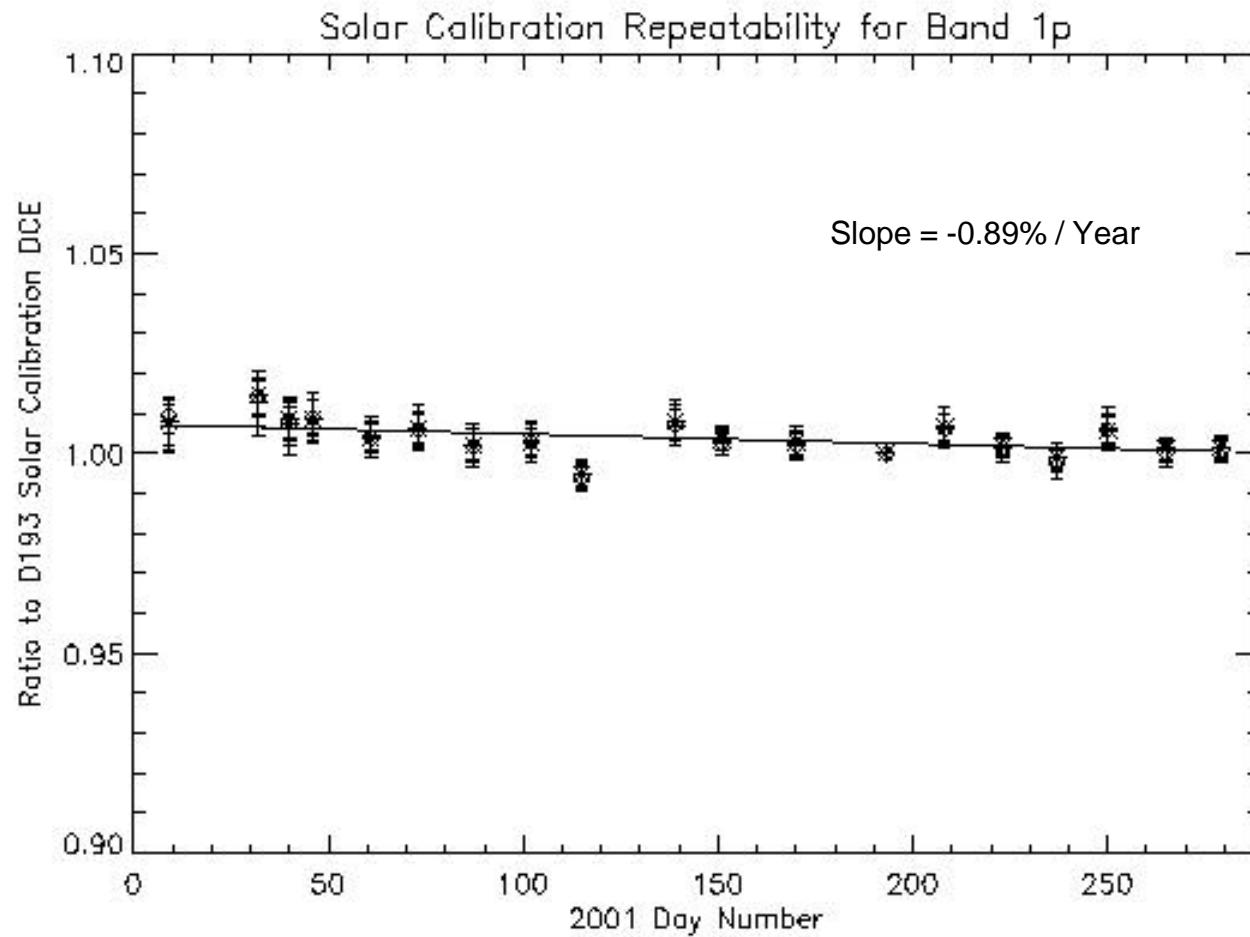


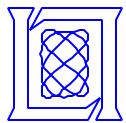
## Solar Calibration



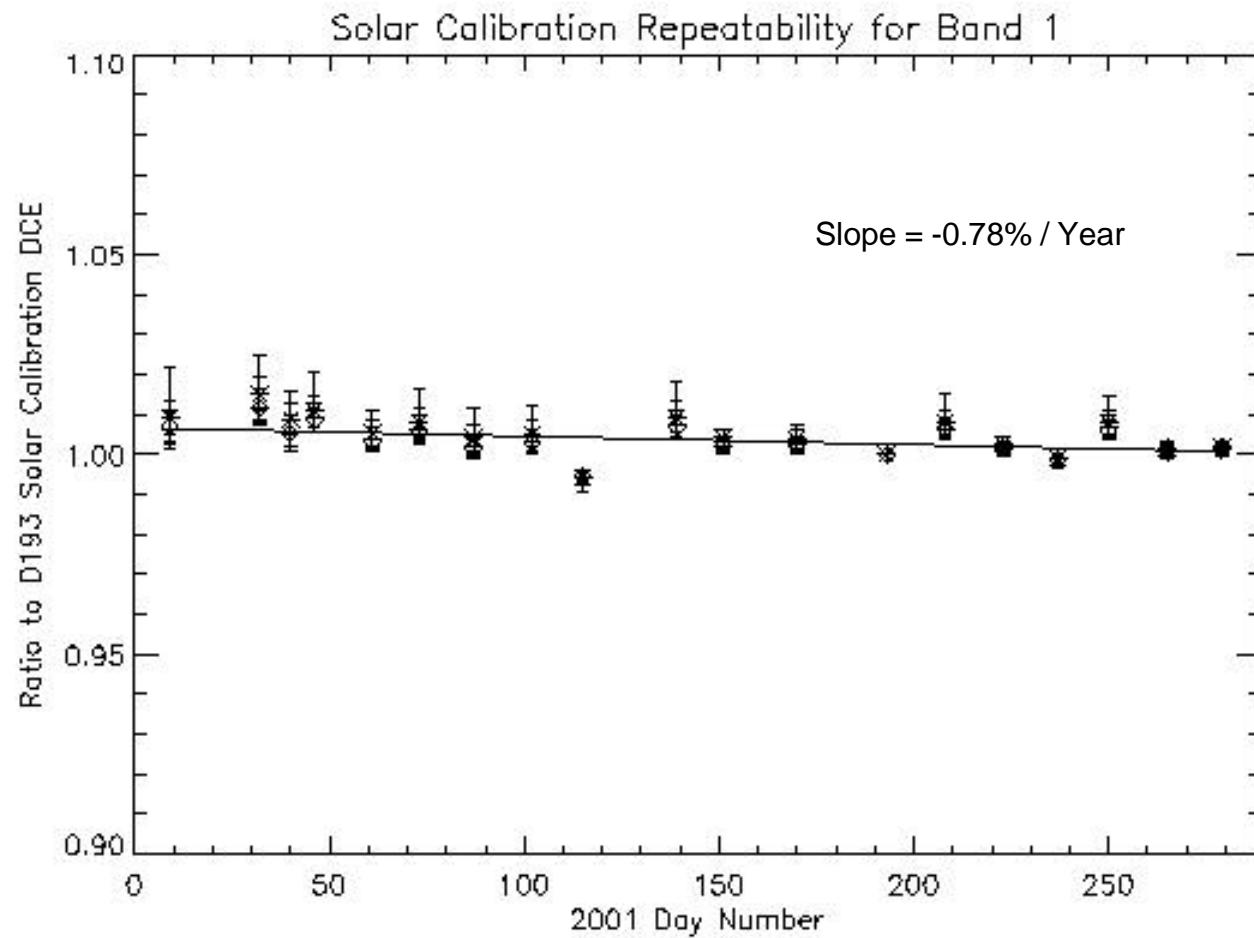


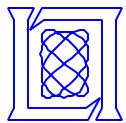
# Stability - Band 1p



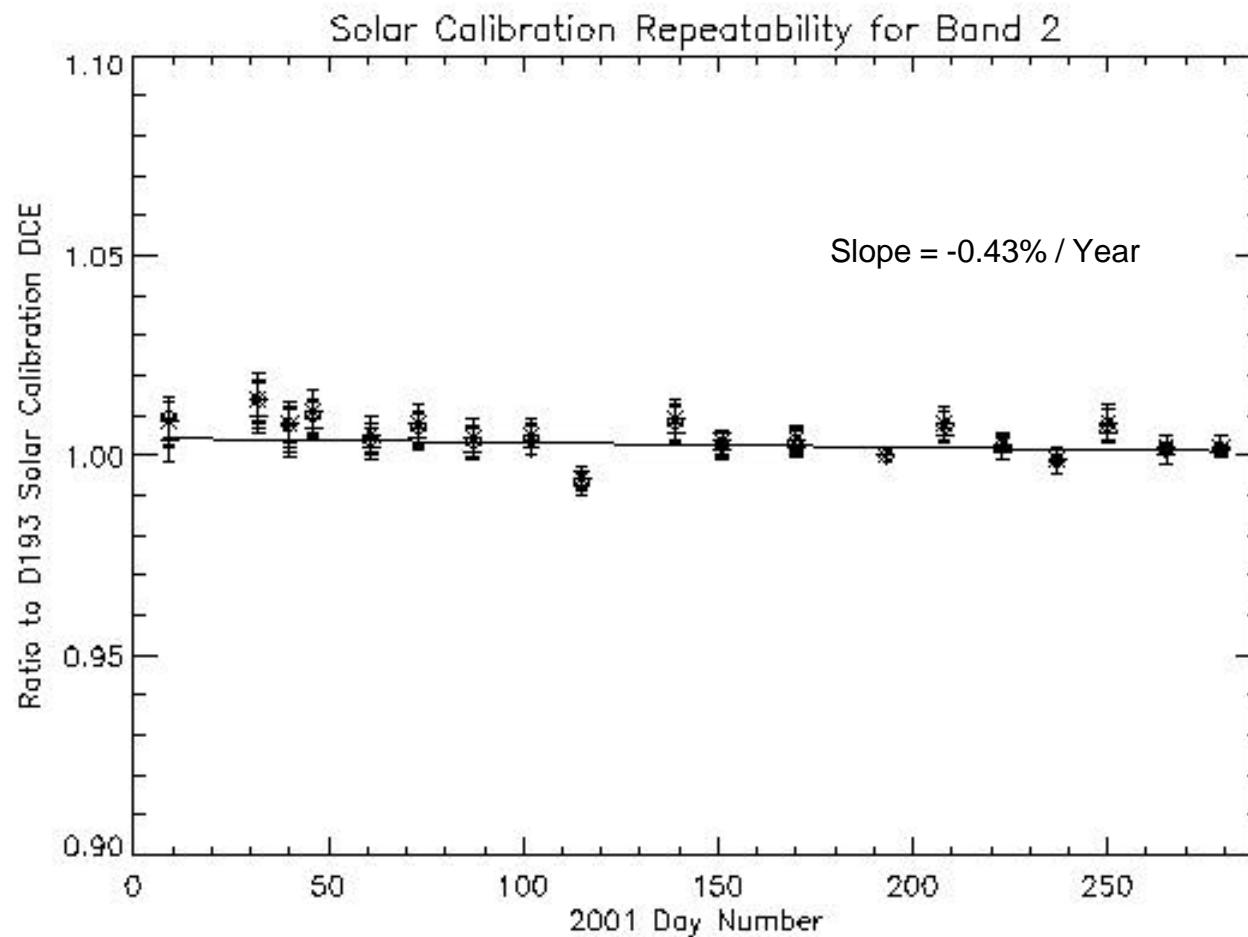


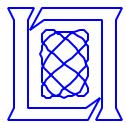
# Stability - Band 1



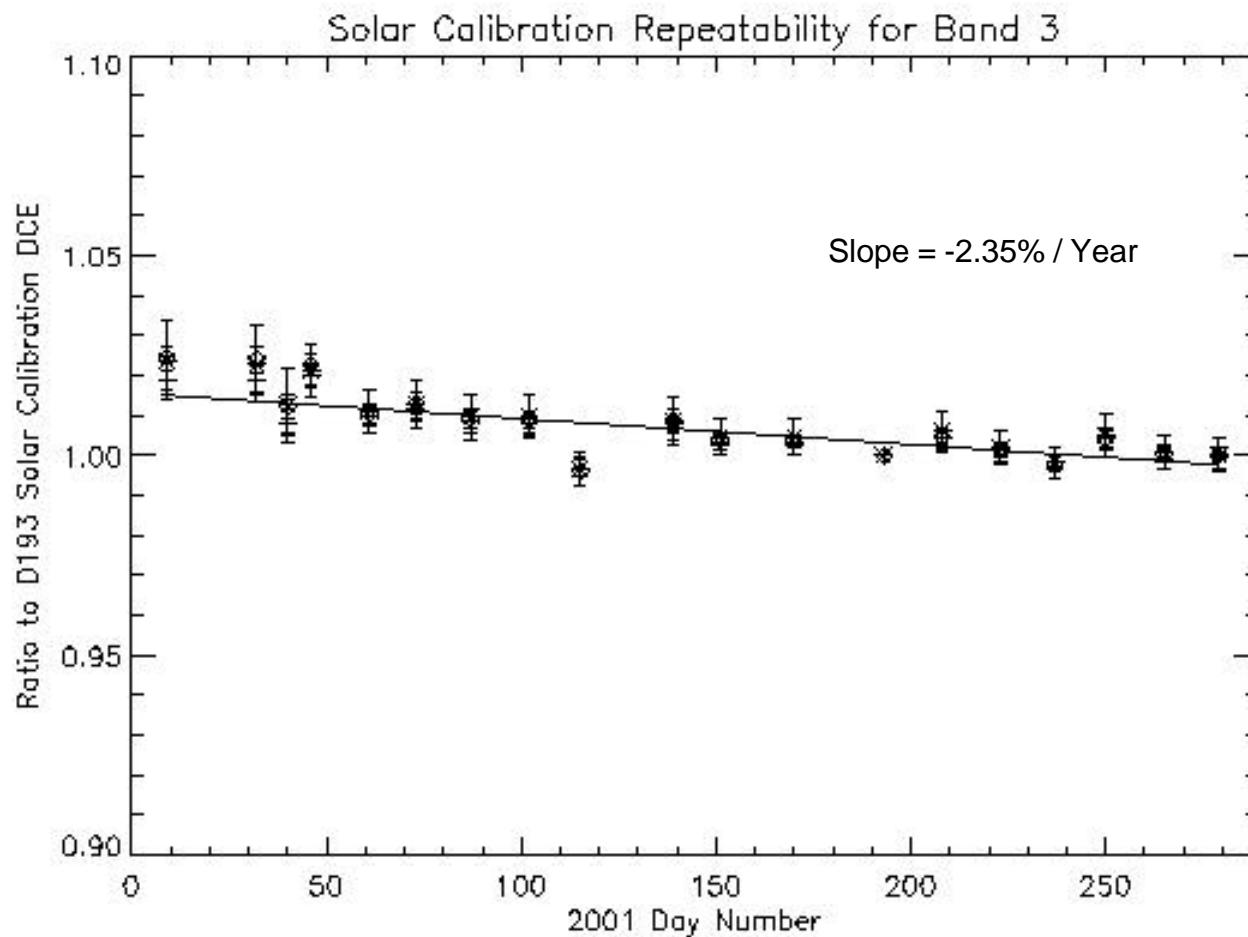


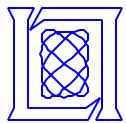
# Stability - Band 2



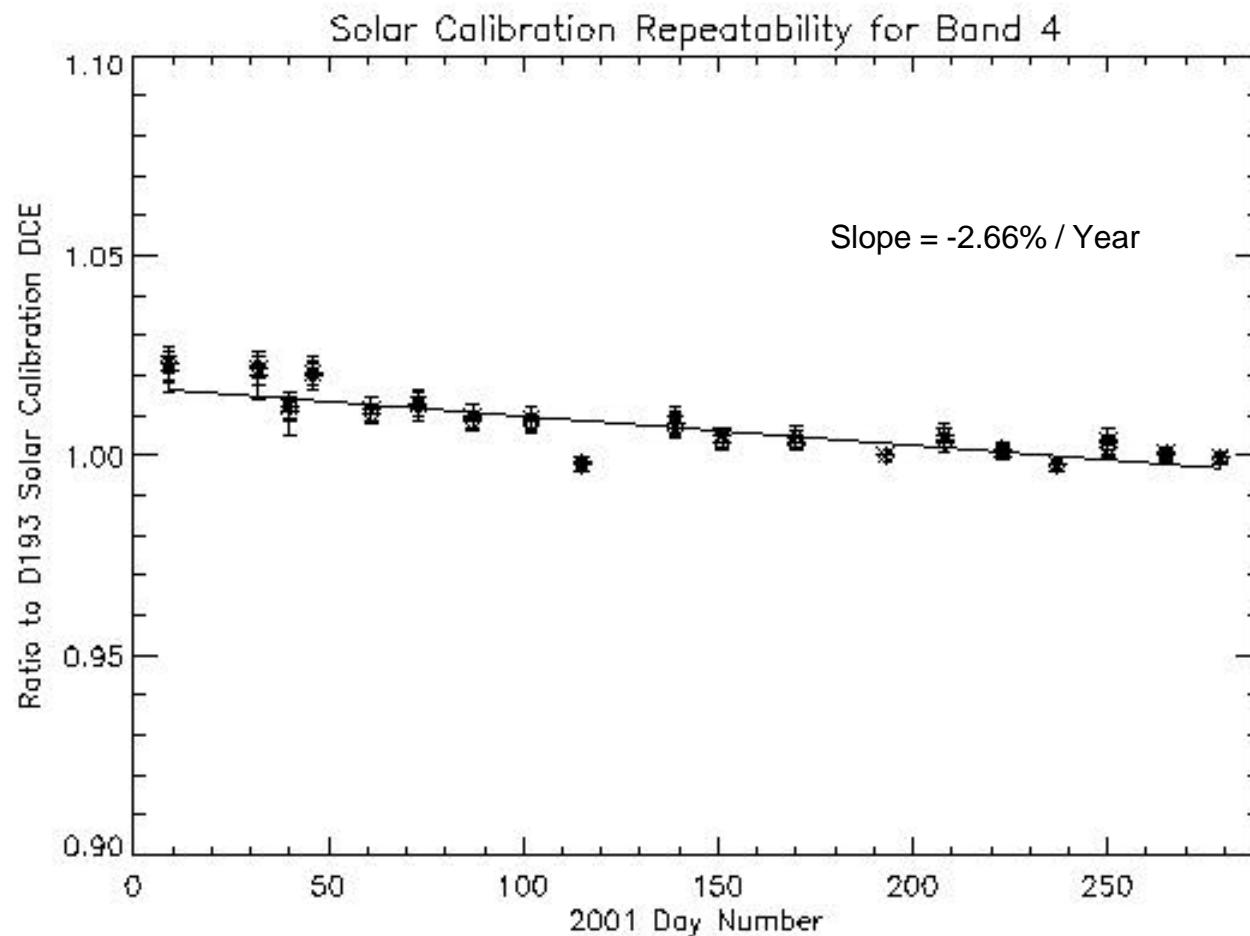


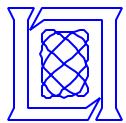
# Stability - Band 3



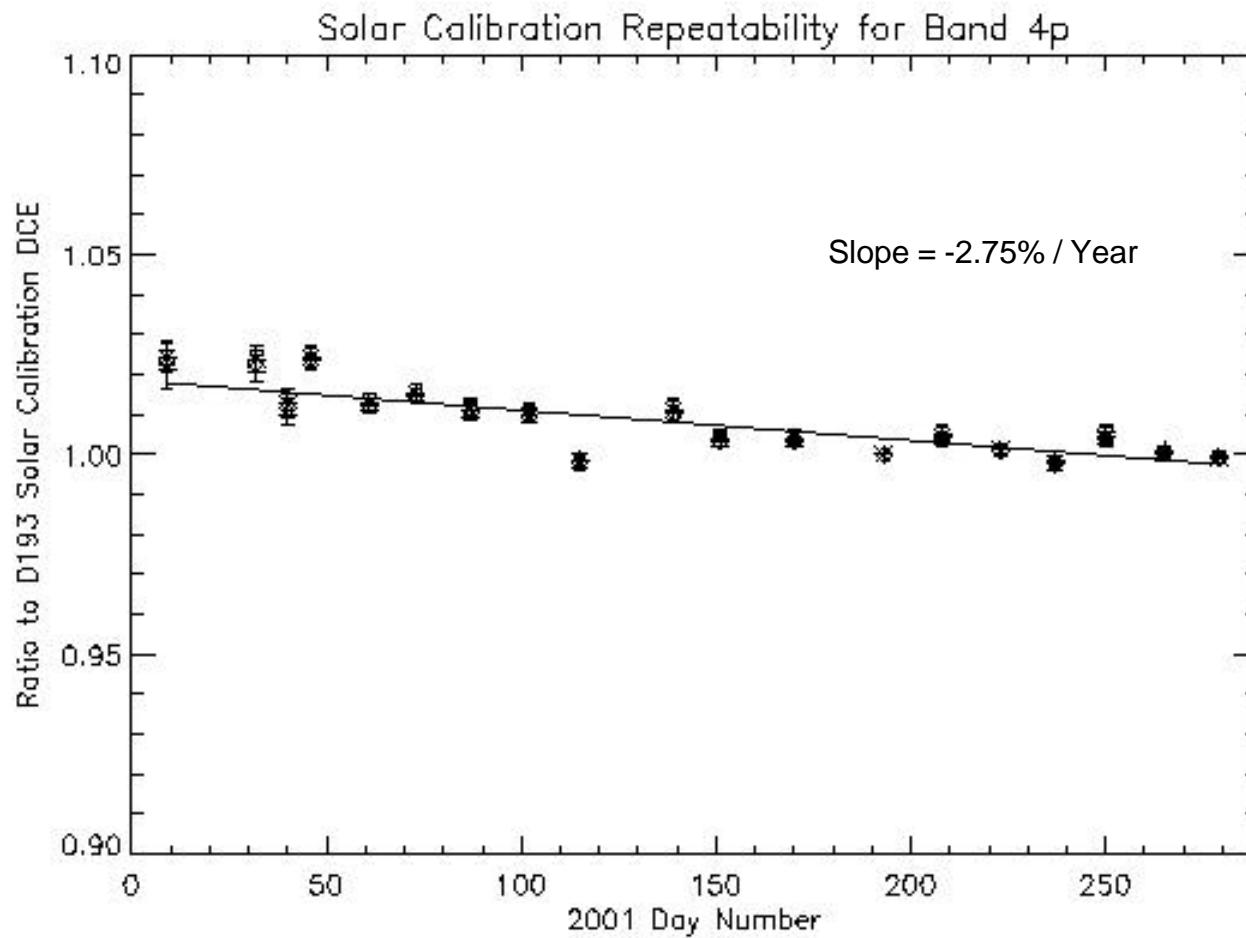


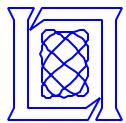
# Stability - Band 4



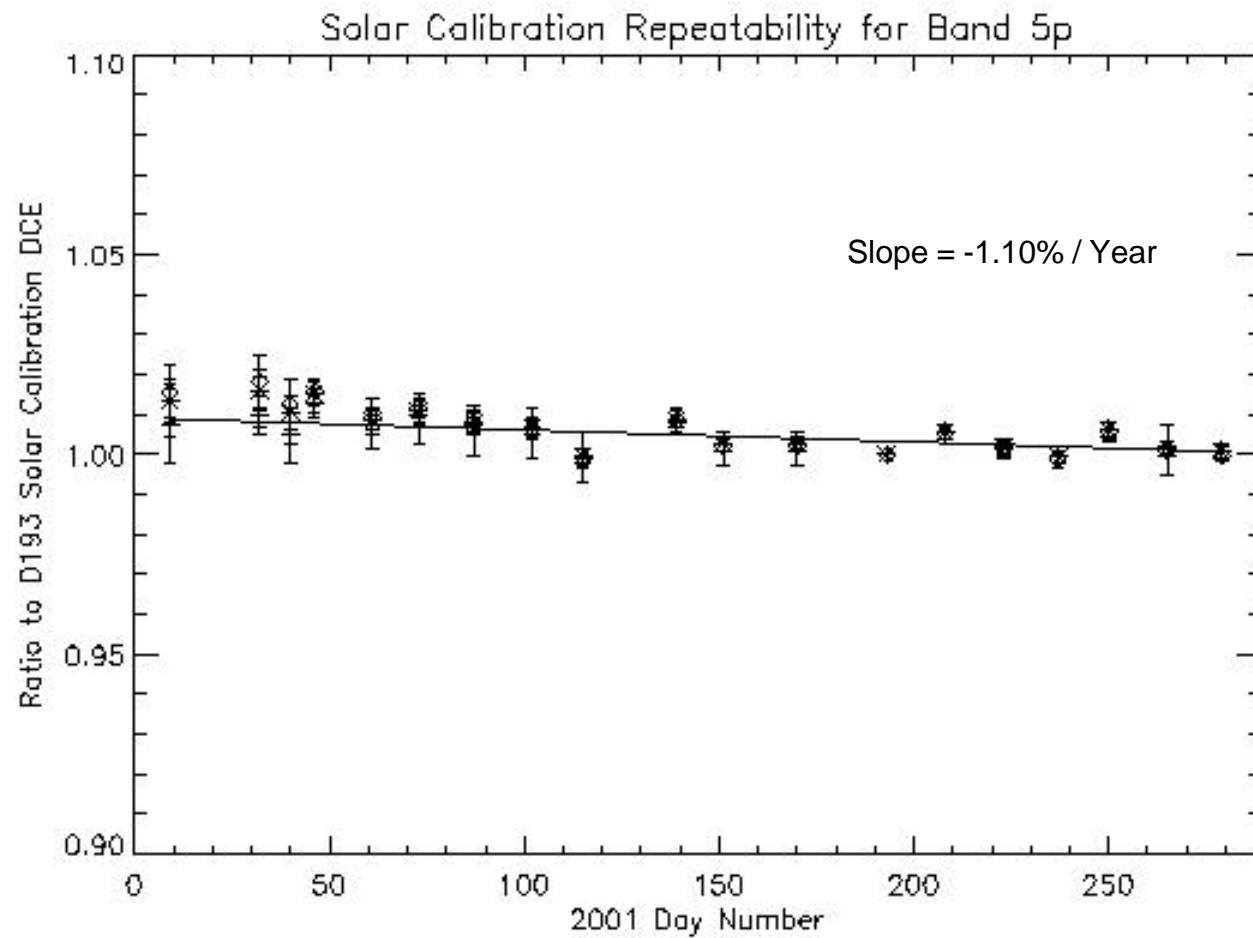


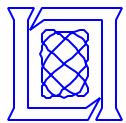
# Stability - Band 4p



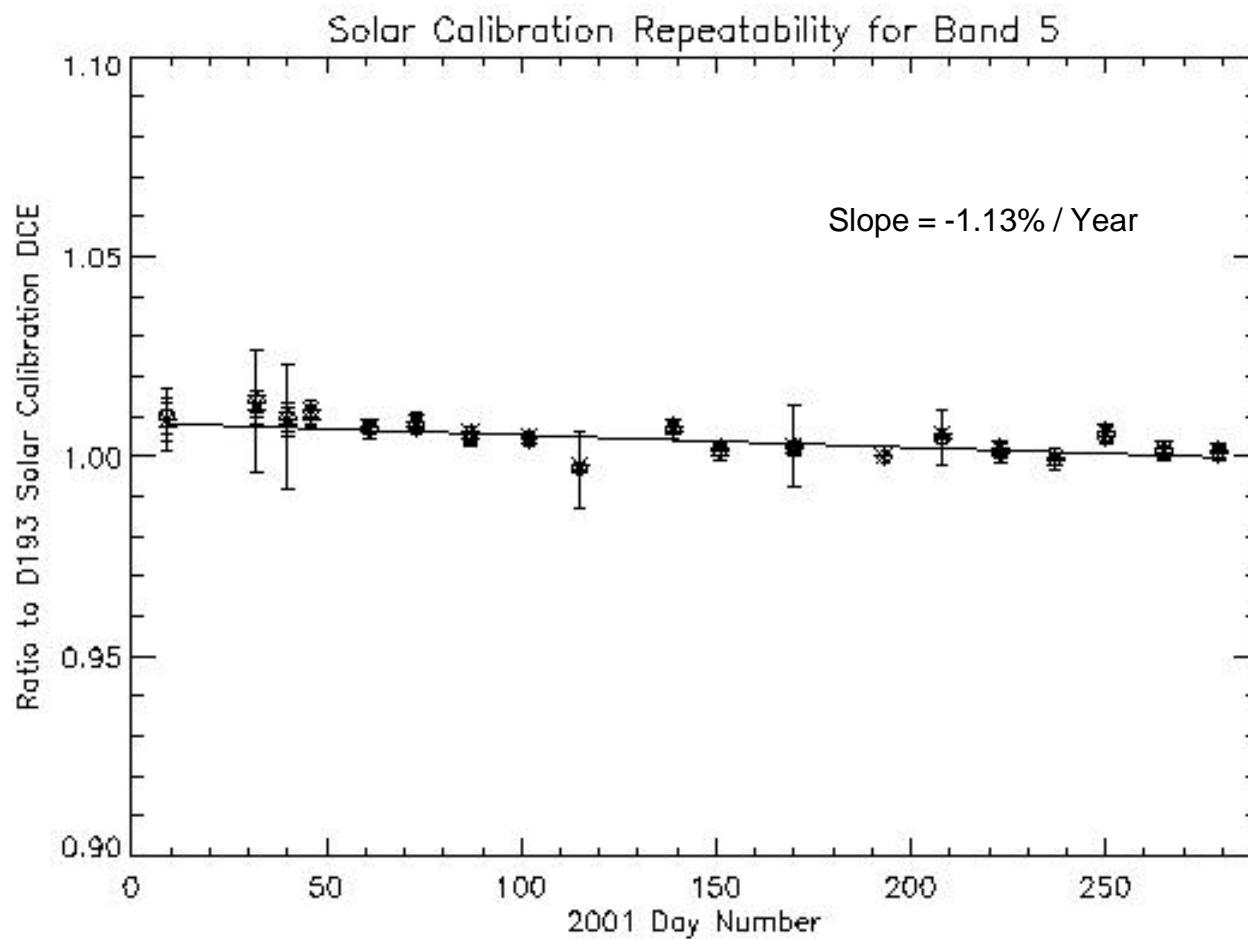


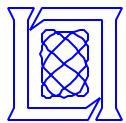
# Stability - Band 5p



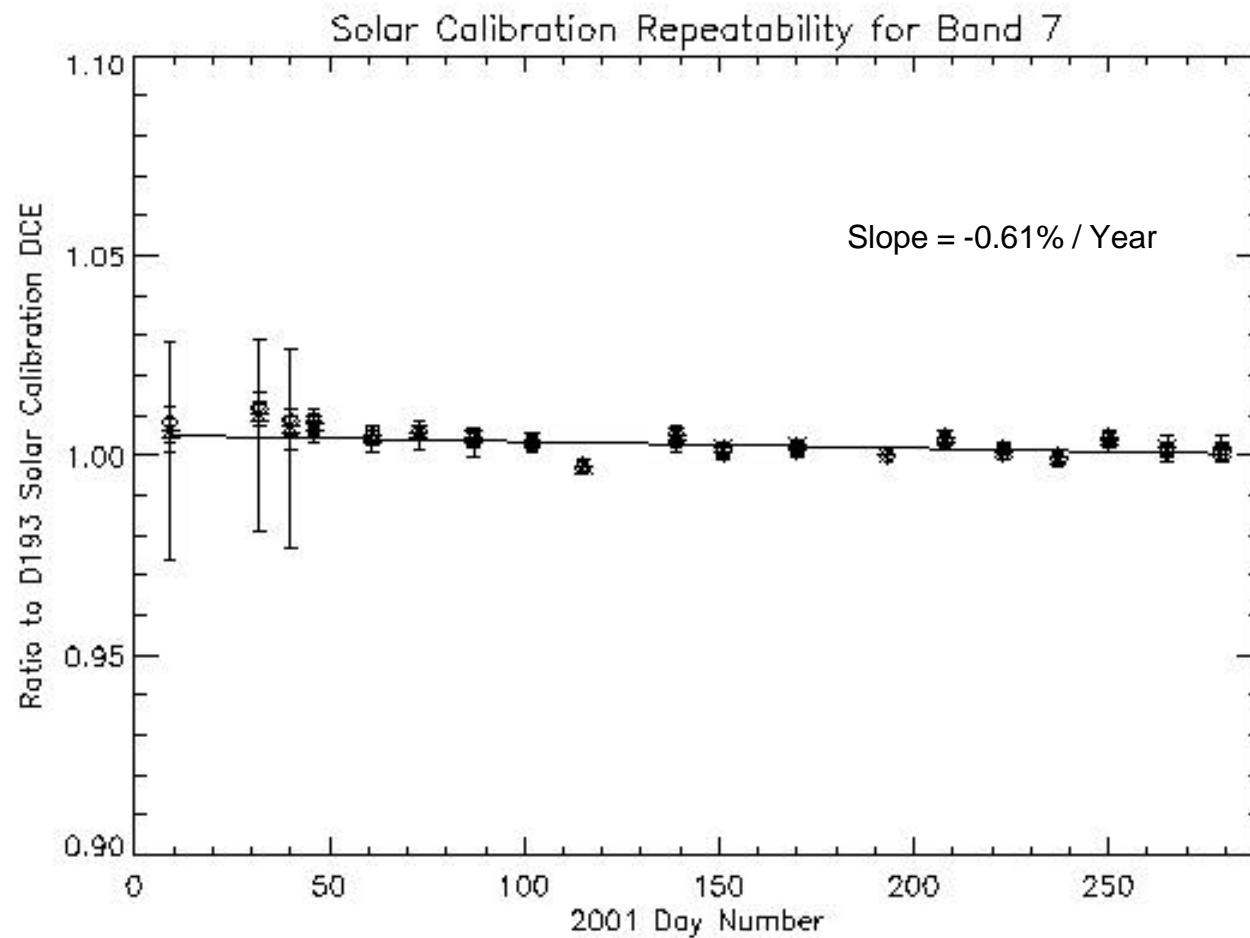


# Stability - Band 5



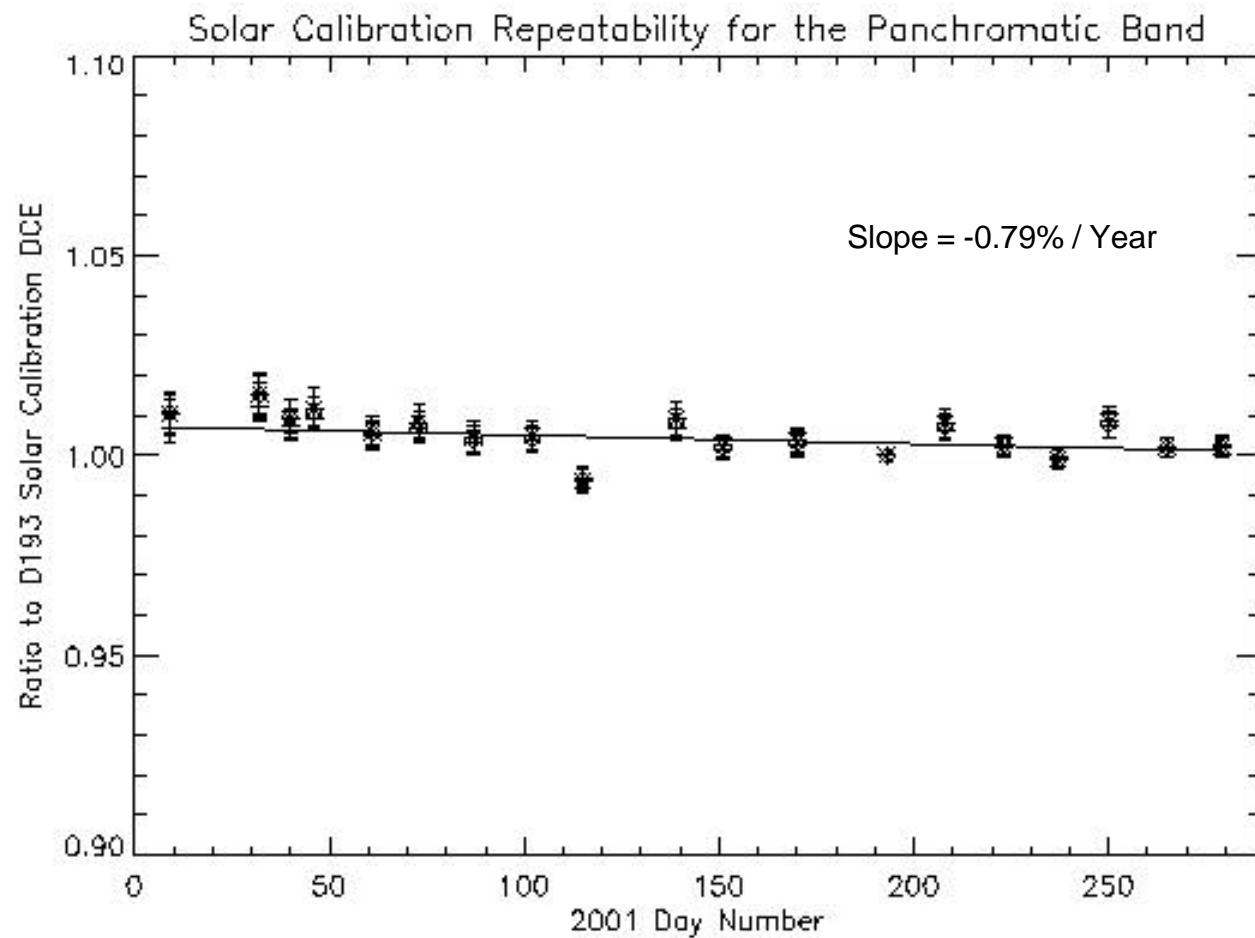


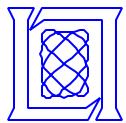
# Stability - Band 7





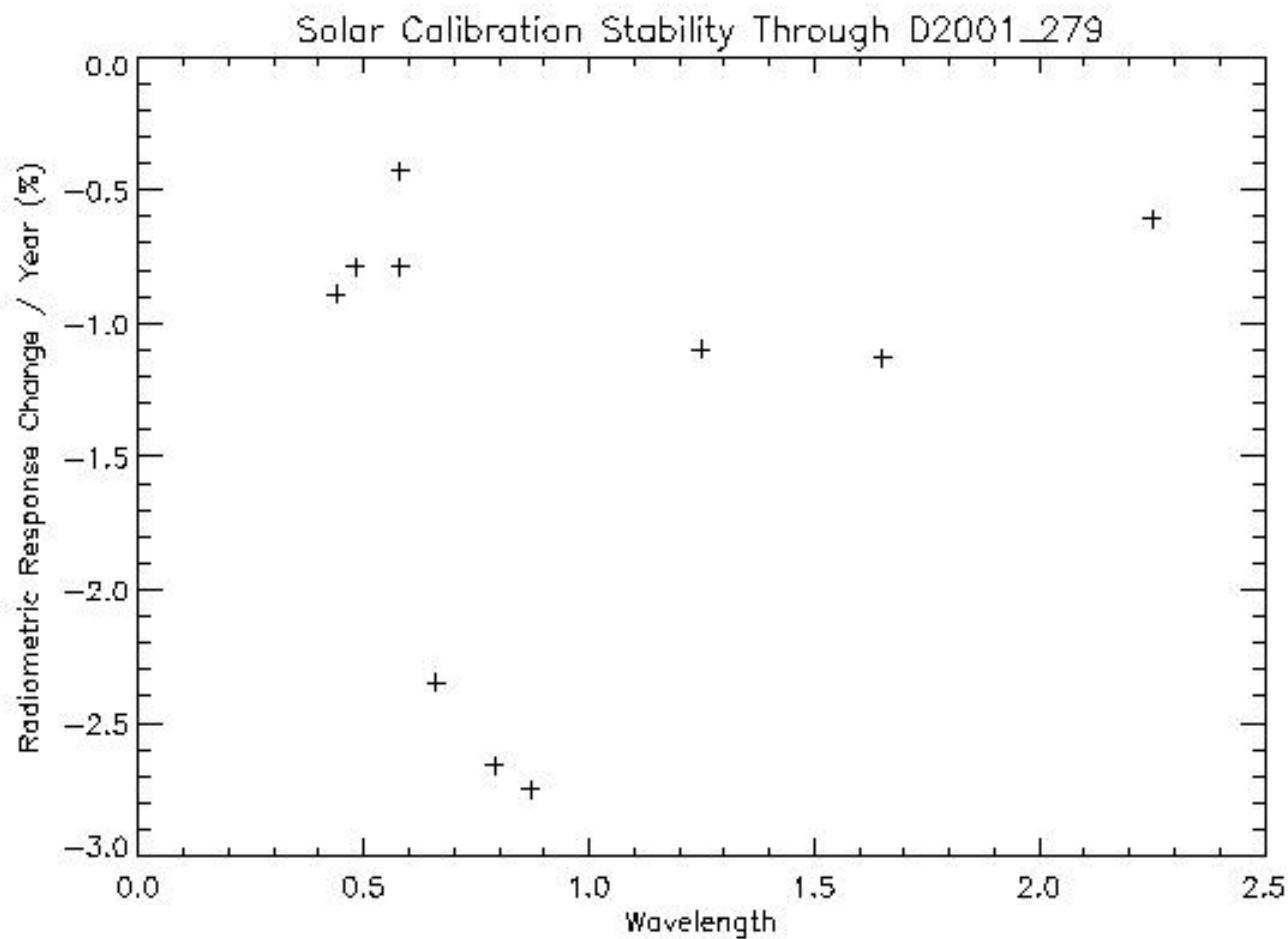
# Stability - Panchromatic Band

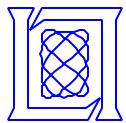




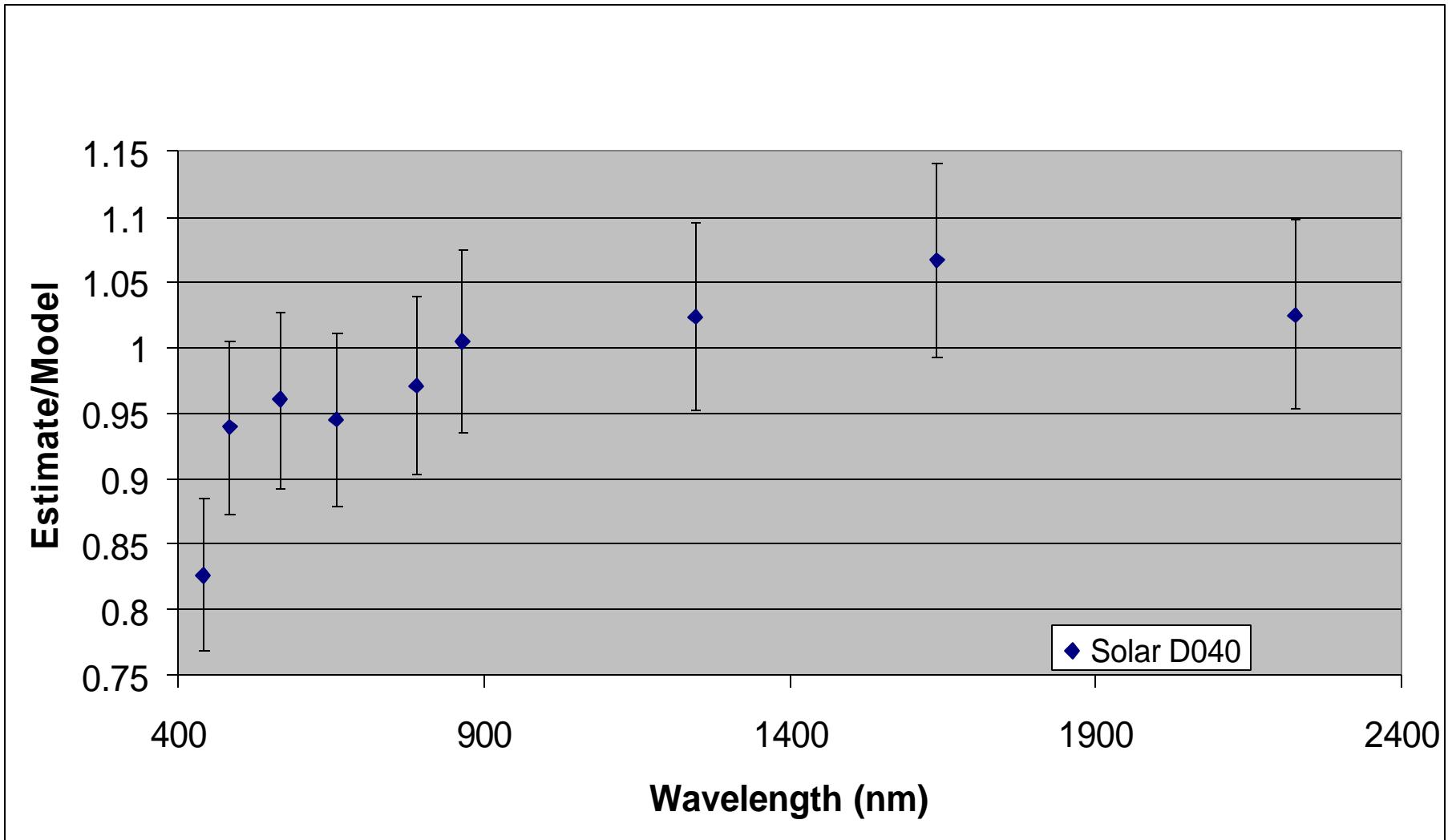
# Stability - Summary

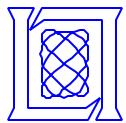
---



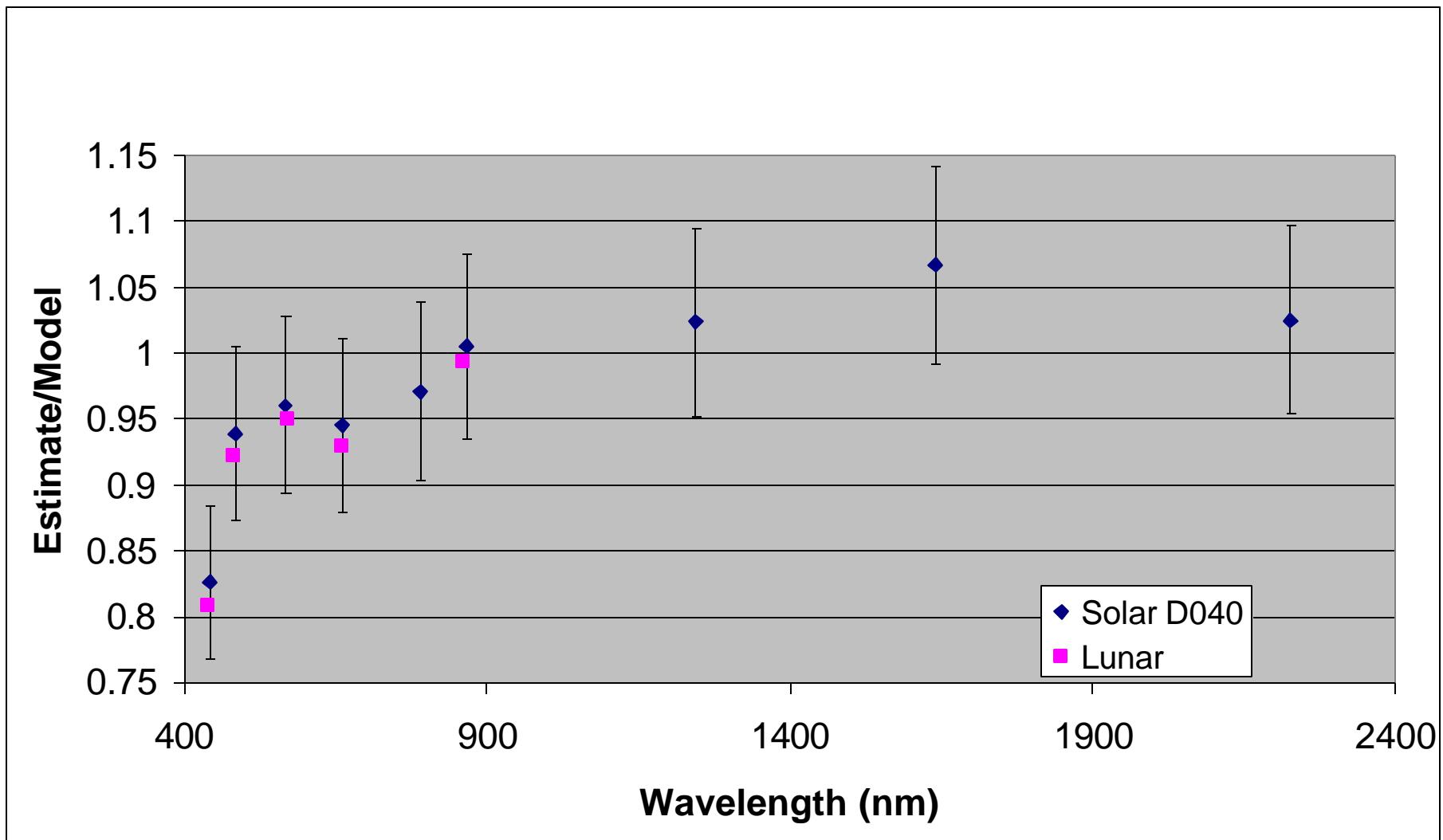


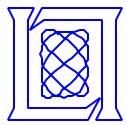
# Absolute Radiometry



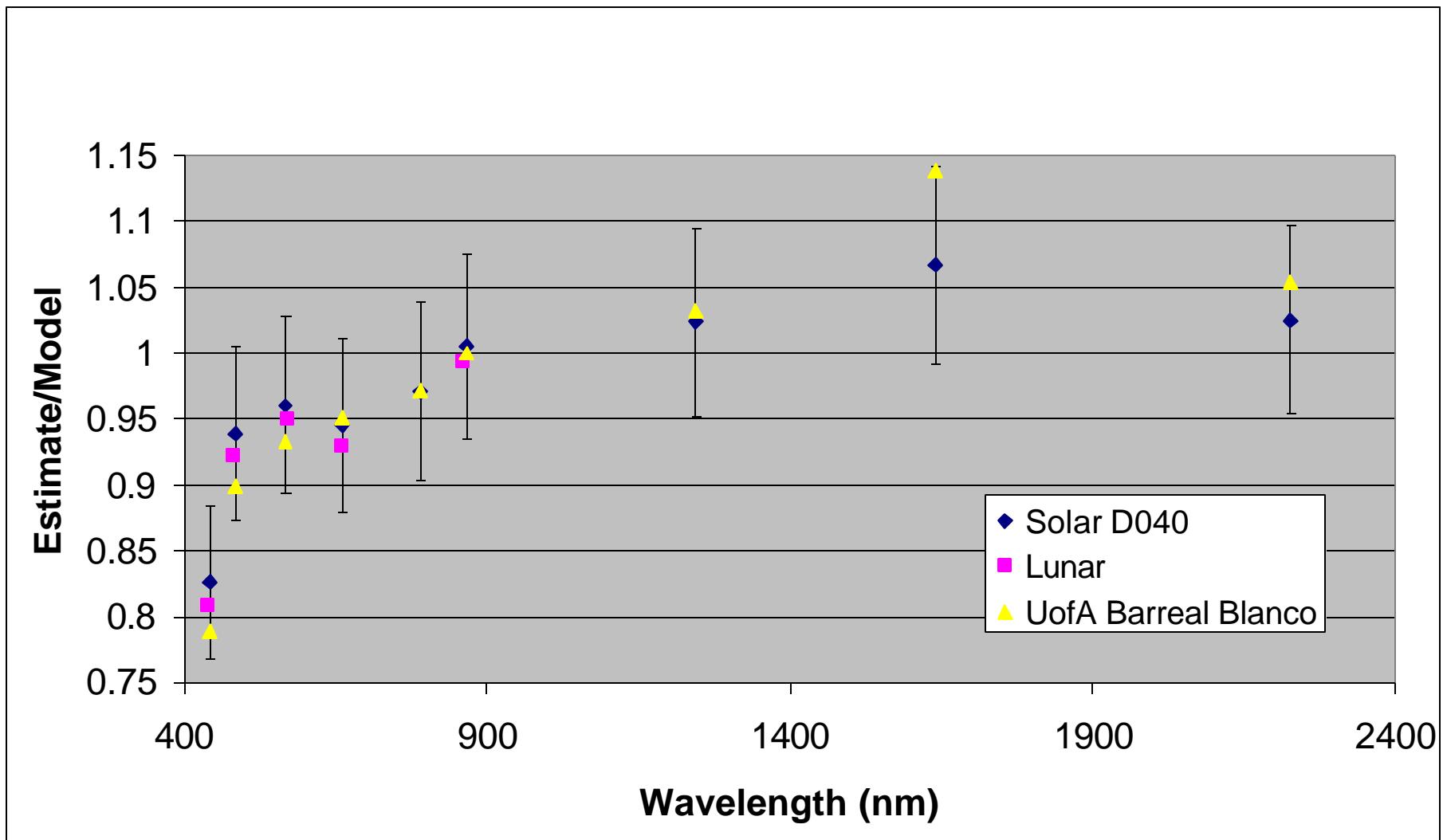


# Absolute Radiometry



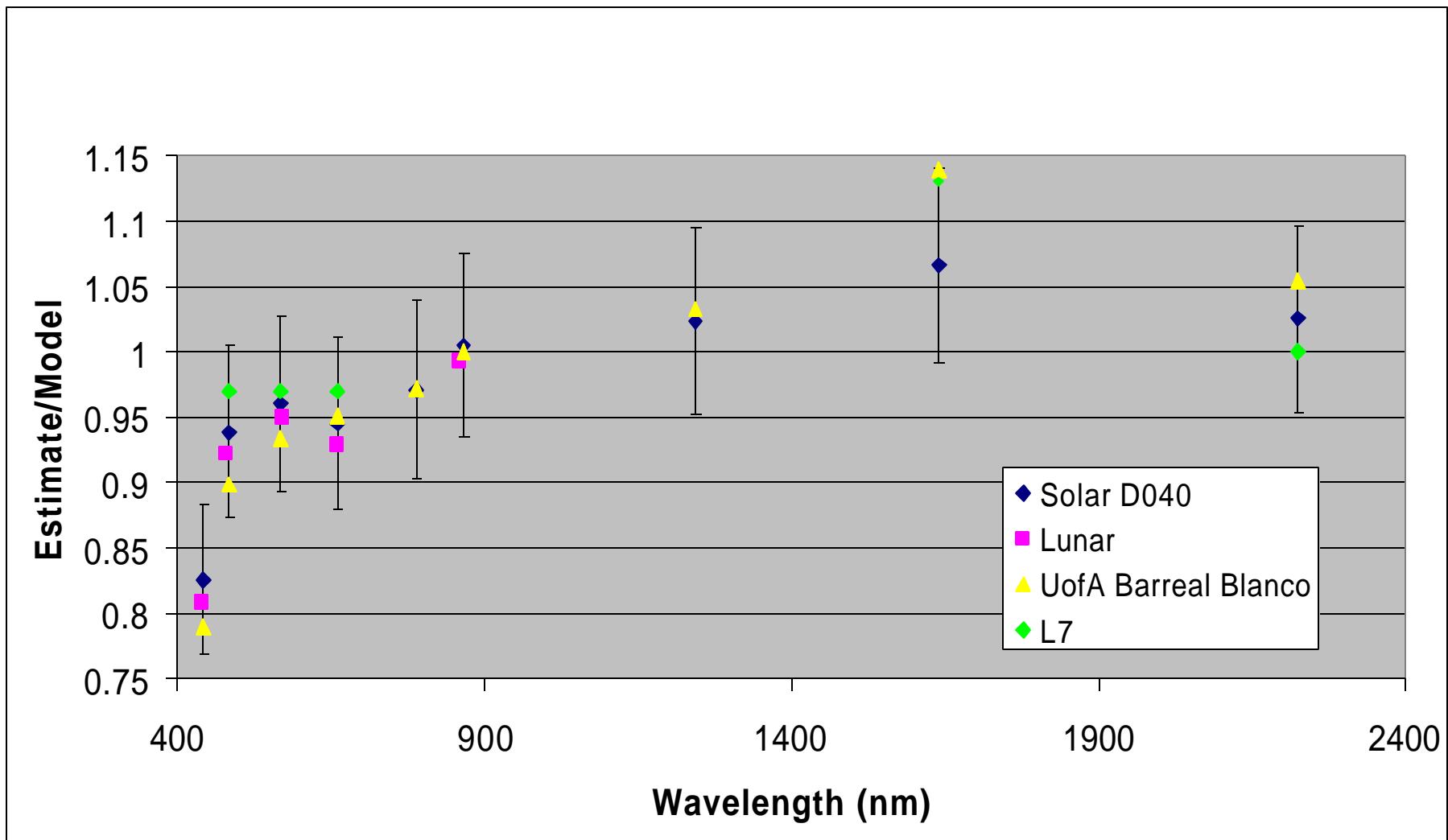


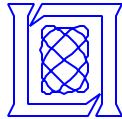
# Absolute Radiometry





# Absolute Radiometry

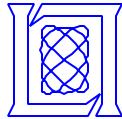




# Sources of Radiometric Error

---

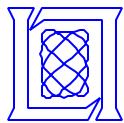
- **Pre-flight calibration inaccuracies**
  - Unlikely due to good agreement between MIT/LL and GSFC measurements of integrating sphere output
- **Change in instrument response since ground calibration**
  - Contamination
  - Difficult to determine
- **Stray Light**
  - Expected stray light effects during manufacturing of mirrors



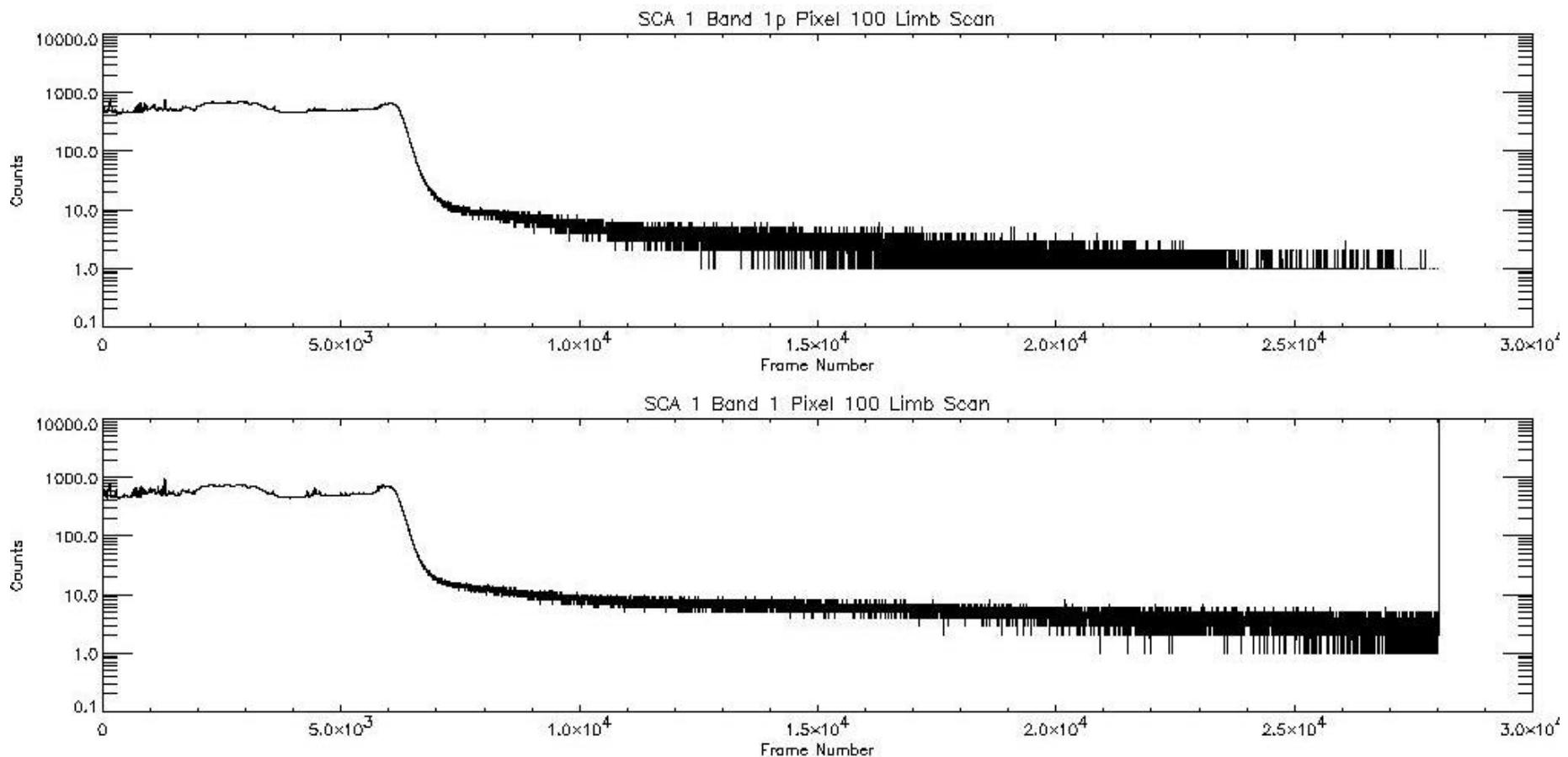
# Stray Light

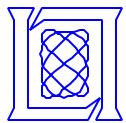
---

- **Telescope delivered did not meet specification on primary and tertiary mirror finish**
- **Lambda Research stray light analysis predicted significant stray light effects for bands 1p, 1**
- **Two source of stray light have been identified**
  - Reflected light from black structure and baffles
  - Mirror scatter
- **Analysis of on-orbit scenes being used to quantify stray light effects and compare to stray light model**
  - Limb scans
  - Earth scenes of varying intensity and spectral signatures, compare ALI to L7 calibrated data and look for stray light effects

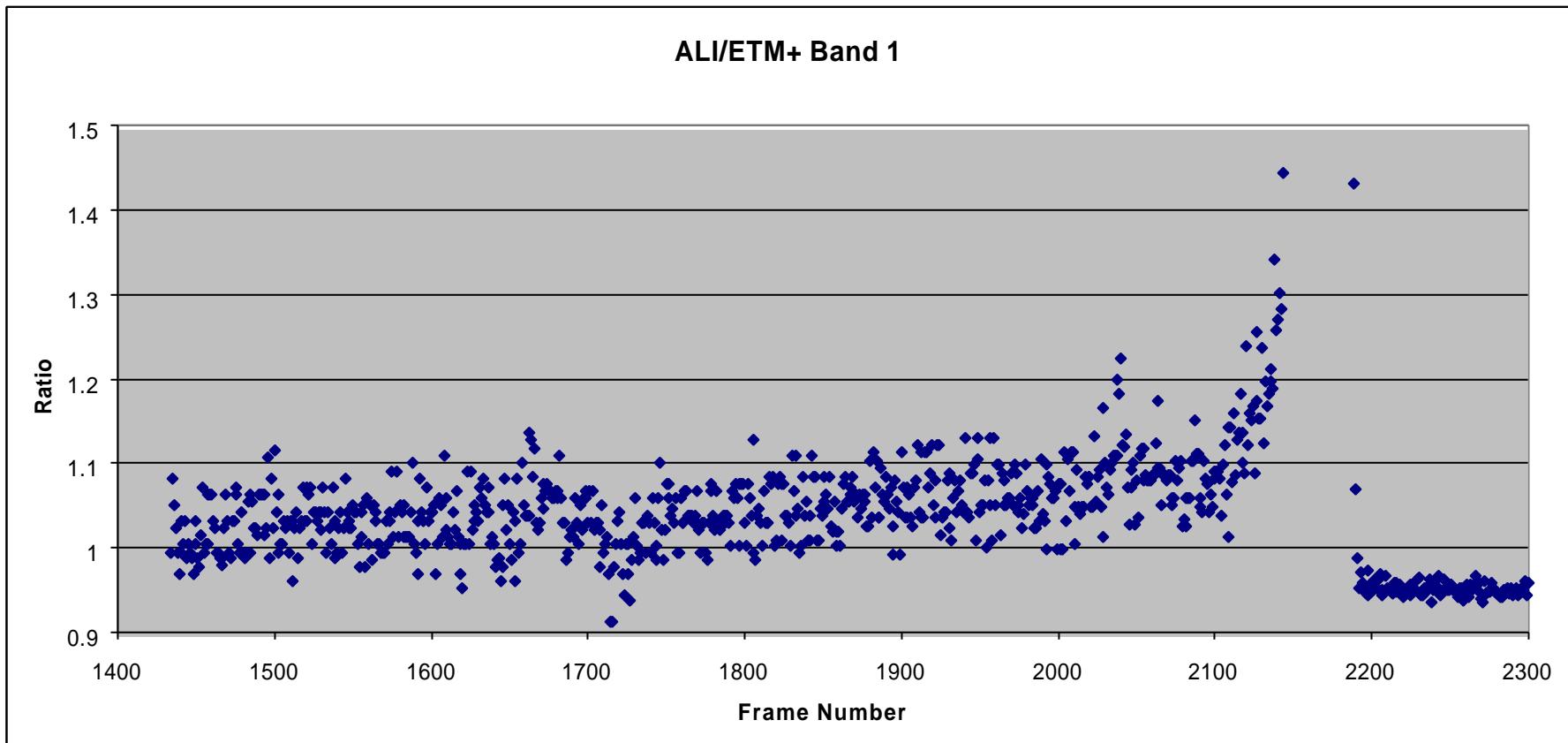


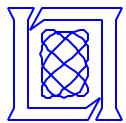
# Earth Limb Scan





# Ross Ice Shelf





# Stray Light Model

---

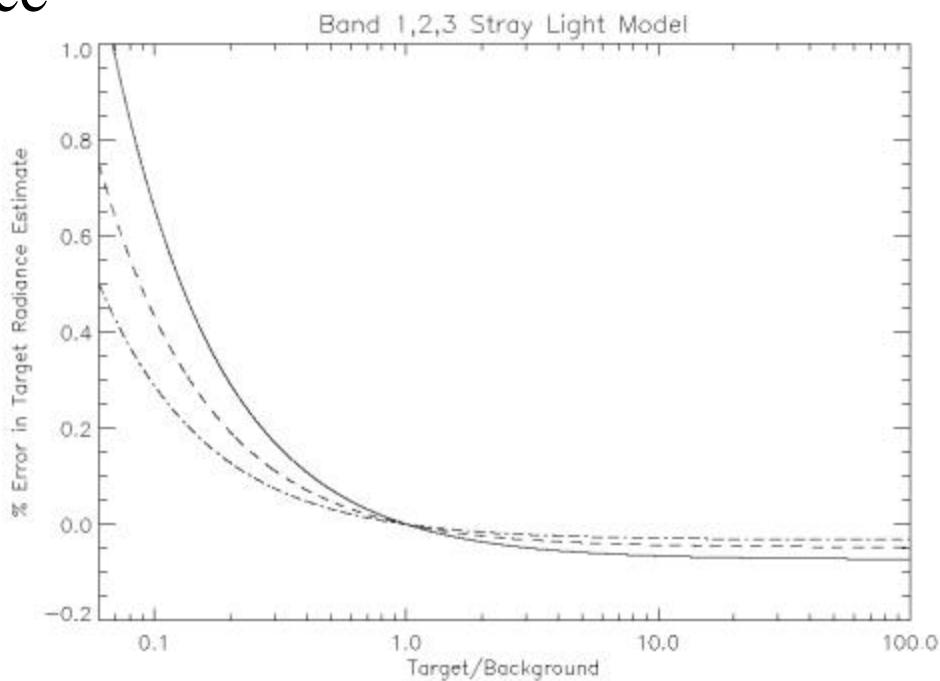
$$\Delta L_T = [s_B / (1 - s_T + s_B)] [L_B - L_T]$$

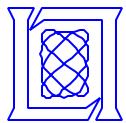
$s_T$  = Total integrated scatter of target region (%)

$s_B$  = Scattered light from background region (%)

$L_B$  = True background radiance

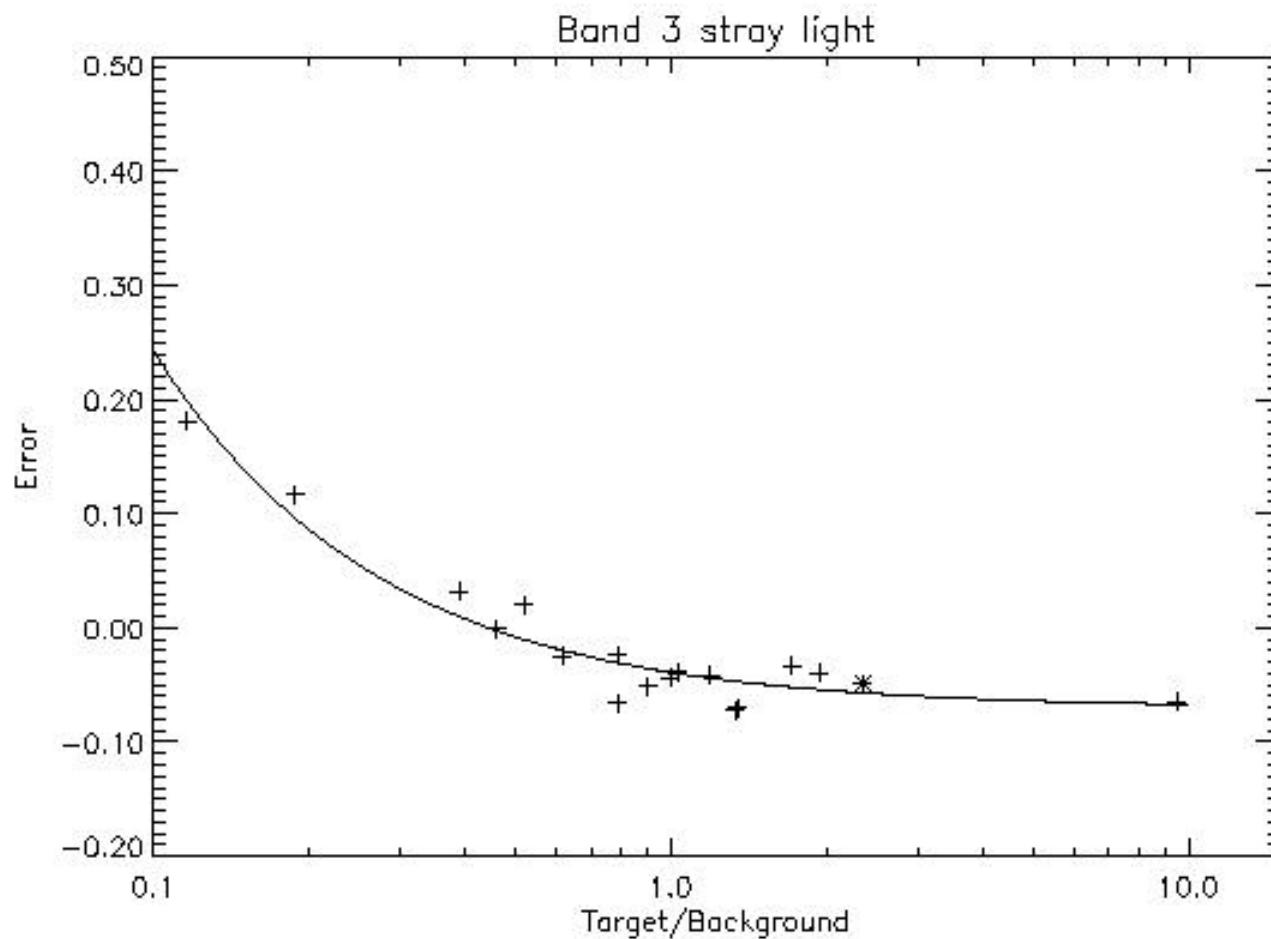
$L_T$  = True target radiance

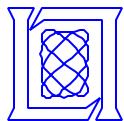




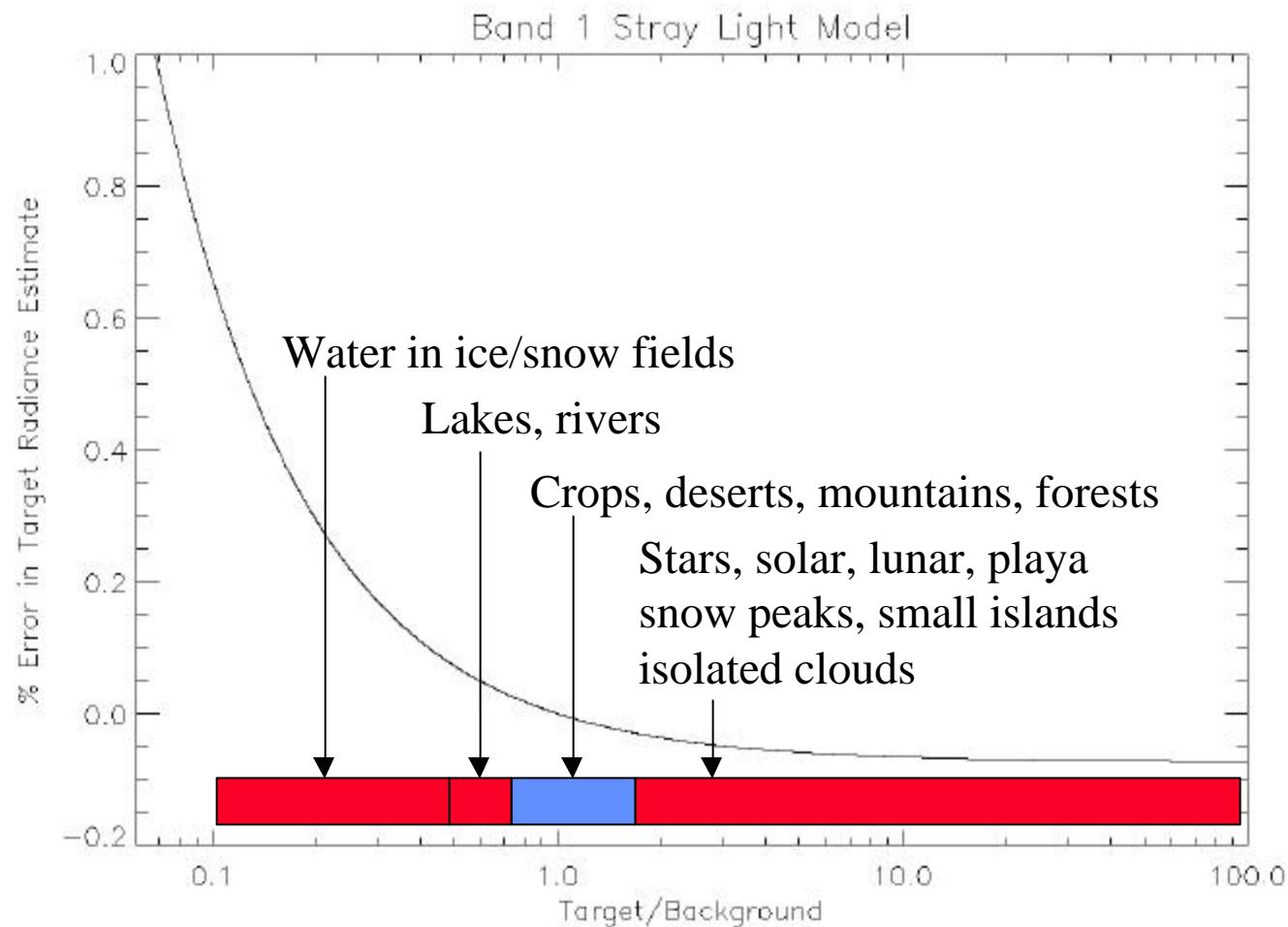
# Stay Light Data - Band 3

---





# Band 1 Stray Light Model

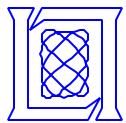




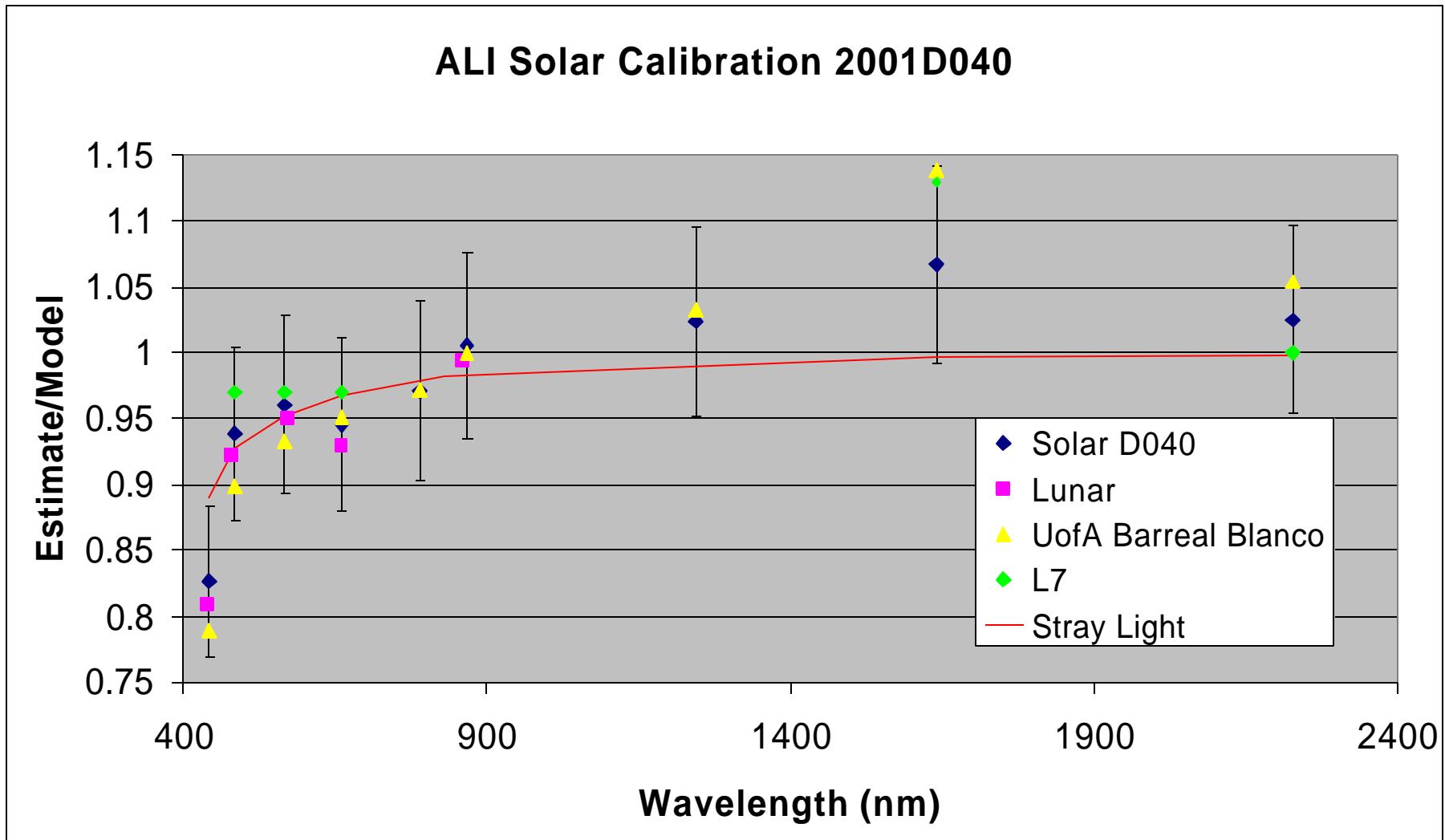
# Stray Light Characterization Summary

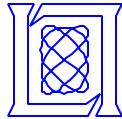
---

- Four Earth limb scans have been taken
- Analysis confirms two sources of stray light
  - Mirror scatter
  - Reflected light from black structure and baffles
- Levels are close to predicted values
- Need better data on diffuse reflectivity of Aeroglaze Z306
- Effects on radiometry and image quality are being quantified
- Stray light model parameters are being derived by comparing ETM+, Ground Truth, Hyperion simultaneous observations with ALI data
- Stray light model predicts minimum impact of stray light for most scenes
- Largest impact of stray light will be for small, dark targets within large, bright background (e.g. lakes in deserts, rivers in snow regions)



# Radiometric Calibration

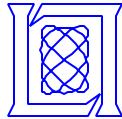




# Outline

---

- **Radiometric Calibration**
  - Review of MIT/LL Integrating Sphere System
  - Technique
  - Analysis
  - Results
  - Landsat Transfer Radiometer Study
- **Flight Validation**
  - Techniques
  - Results
    - Stability
    - Absolute Radiometry
  - Stray Light
- **Summary**



# Summary

---

- All ALI detector radiometric responses have been accurately fit to linear functions.
- Pre-flight absolute radiometric calibration of all ALI bands meet 5% requirement.
- Intercomparison of ALI/ETM+/Hyperion data consistent with stray light model.
- Stray light will have significant effect on radiometry of small dark regions embedded in much brighter average background.
- Additional analysis of the effects of stray light and additional intercomparison of ALI/ETM+/Hyperion data over a variety of scenes and radiances is needed to complete radiometric performance assessment.